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Investigations of herbicide granule distribution

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Investigations of herbicide granule distribution

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INTRODUCTION

Use of herbicides has made possible improved weed control, weed control under adverse conditions, and flexibility in selecting weed control practices. Herbicide rates are established by extensive field testing by industry, experiment station and USDA personnel. The recommended rates include a wide safety margin and are usually in excess of the amount needed for control. This is partially due to the uncertainty of weather following application and to the variability in conditions of the microsites to which the herbicide is applied. A large part of the excess is necessary because the output of conventional application equipment fluctuates considerably with time and is nonuniform across the applicator swath.

The annual loss of pesticides wasted by nonuniform and inefficient application for the period 1951-1960 was estimated at $64,847,000 (USDA, 1965). The need for uniform and efficient application of pesticides and for development of improved application equipment has been referred to by Day (1972), Starker (1959), Frear (1972), Carleton and others (1960), Farmery (1970), Goehlich (1970), Price and Gunkel (1965), Gunkel and Hosokawa (1964), Holly (1970), Whitehead and others (1970), and Danielson (1960).

Uniform and efficient application should reduce the amount of herbicide needed and minimize objectionable side effects such as persistence and movement to undesirable locations.

The problem is to place the minimum required amount of chemical where needed, with the least amount going elsewhere, and at a reasonable cost

(Carleton and others, 1960).

To effectively manipulate the weed/herbicide environment and to design applicators to distribute herbicide granules effectively, it is necessary to know how the environment influences the area-of-control of individual granules and how the uniformity of distribution of many granules over an area affects the control of weeds in that area.

OBJECTIVES

The objectives of this research were to:

1. Describe the area-of-influence of an individual herbicide granule and evaluate effects of weather, granule placement, soil conditions, and weed seed location on the area-of-influence.
2. Determine a method of describing uniformity of spatial distribution of herbicide granules.
3. Establish relation between uniformity of spatial distribution of herbicide granules, herbicide rate, and weed control.

REVIEW OF LITERATURE

Herbicide Granules

Herbicides in granular form were first used on a large scale in the mid-1930's (Rake, 1957). The use increased slowly until the 1950's when the production of organic herbicides became extensive. By 1960 the full impact of the granular concept was felt in the Corn Belt with 10 commercial companies marketing 2,4-D and with several other compounds being marketed with a volume in millions of pounds (Spurrier, 1960).

Data showing the use of pesticides in the United States are limited. However, organic herbicide production was 390,665,000 lb in 1970 with domestic sales totaling 308,112,000 lb at an estimated value of $497,954,000. An indication of the increase in granular formulations is the trend in consumption of Fuller's Earth (attapulgite clay) in pesticide formulations from 190,764,000 lb in 1963 to 383,376,000 lb in 1970 (Mahan and others, 1972).

Most granular herbicides are formulated by placing active material on inactive carriers such as clay, sand, vermiculite, etc. Many materials have been tried, but clays are most commonly used because of their high sorptive capacity. Inherent chemical characteristics of some compounds make possible formulation of granules with as high as 35% active ingredient (Spurrier, 1960).

Granular formulations of herbicides can offer the following advantages (Spurrier, 1960; Klingman, 1961; and Rake, 1957):

1. Improved characteristics and ease of handling.
2. Elimination of water handling.
3. Reduced labor.
4. Lower cost of application equipment and less operator skill required.
5. Elimination of mixing errors.
6. Increased selectivity.
7. Reduced drift.
8. Reduced volatility of some compounds.
9. Improved distribution due to uniformity of particle size.
10. Reduced microbial decomposition of active ingredient.

Some disadvantages listed by Klingman (1961) are:

1. Increased shipping charges since more material must be handled.
2. Some granules are easily moved by wind and water.
3. Application is seldom as uniform as with sprays.
4. Not well adapted for foliage treatment.

Herbicide Movement from Granules

When evaluating uniformity of application, it is important to consider what area of surface is the basic unit (Holly, 1970). What appears uniform on a square meter scale might be very nonuniform on a square millimeter scale. The area over which a weed seedling will encounter the herbicide determines the satisfactoriness of the application. This area is dependent on the plant and the herbicide and also on environmental conditions.

Mullins (1965) investigated the movement of 2-chloro-N,N-diallylacetamide (CDAA) from a granule into soil. Chemical concentration was determined by gas chromatographic analysis. He found that soil moisture conditions, air movement, and incorporation influence the concentration pattern of the herbicide. He also found that surface applied water was not necessary for movement of CDAA. Laboratory experiments were conducted by Molnau and others (1973) to evaluate soil moisture content, air temperature, relative humidity, and depth of incorporation on the shape and size of the soil volume into which 2-chloro-N-isopropylacetanilide (propachlor) moves from a granule. They found soil moisture and temperature to be the most important factors influencing movement.

Molnau and others also investigated the concentration of propachlor in the soil of small watersheds. They found large variations in concentration among locations even when care was taken in applying the herbicide. Measurements of application taken the day the herbicide was applied gave concentration extremes in the top inch from 1.8 to 8.2 ppmw with the average 5.8 ppmw for one watershed and extremes of 5.4 to 14.7 ppmw with an average of 9.4 ppmw for a second watershed.

Propachlor moved downward and laterally from the granule in soil at or below the wilting point for both surface and incorporated granules. At higher moisture contents, the chemical moved upward for incorporated granules and horizontally for surface applied granules.

Ritter (1971) also found a wide range of concentrations of atrazine, propachlor, and diazinon in the surface of soil when the pesticides were applied in a conventional manner. He found the diffusion rates of the pesticides studied to increase with increasing soil moisture content and temperature. In 8 days the movement, however, was less than 1 cm.

Description of Particle Distribution in Two Dimensions

The uniformity of seed distribution when sowing was investigated by Khaichenko (1968). He argued that the amount of seed on a small area of a seeded field is a random function of the coordinates of the area and that the random function is characterized by the mathematical expectancy and the correlation function. The mathematical expectancy is the average amount of sowed seed on an elemental area and the correlation function characterizes the spread of the relative mean value and the association between the amounts of seed sowed on different areas. Khaichenko expressed difficulty in finding the rule of distribution of the random function. However, he felt that since a large number of factors influence the distribution and none dominate each other to a large degree the distribution is subject to the normal law. Since the normal law is characterized by the mathematical expectancy and the correlation function, he felt that these values would suitably describe the distribution of seeds during sowing.

Several techniques have been used to describe the distribution of individuals in a plant population. The spatial distribution of individuals is usually classified as being either random, aggregated, or regular. The random distribution follows the Poisson model which says that the probability of finding k individuals in an area depends only on the size of the area and not its shape. If the area is small, the probability of finding more than one individual in the domain is small compared to the site of the area and non-overlapping domains are independent (Stiteler and Patil, 1971). Stiteler and Patil discussed the variance-to-mean ratio of counts of individuals per plot as a measure of spatial patterns in ecological populations. This ratio, which has a value of 1 for a random distribution since the mean and variance of the Poisson distribution are equal, can be estimated by

$$\frac{\Sigma(x_i-\bar{x})^2}{\bar{x}}$$

where x_i is the number of individuals in the ith quadrant and $\bar{x}$ is the average number of individuals per quadrant. They called this relationship the index of dispersion. Stiteler and Patil also discussed Morisita's Index of Aggregation,

$$I_\delta = \frac{n\ \Sigma x_i(x_i-1)}{\Sigma x_i(\Sigma x_i-1)}$$

which is a measure of the diversity of the numbers of individuals per quadrant, x_i. For a random distribution with n quadrants, the expected value of I_δ is 1. It is greater for aggregated patterns and less for regular patterns.

Clark and Evans (1954) used the distance to nearest neighbor to describe the pattern of distribution of a population of plants. The ratio of the observed mean distance to the expected mean distance for a random distribution was used to specify the manner and degree to which the distribution departed from randomness. In a population of N individuals having specified density ρ with distance r to nearest neighbor the mean observed distance is $\bar{r}_A = \frac{\Sigma r}{N}$. If the distribution is random, the expected mean distance is $\bar{r}_E = \frac{1}{2\sqrt{\rho}}$. The ratio $R = \bar{r}_A/\bar{r}_E$ is the degree to which the observed distribution departs from random expectation. For random distribution R = 1, for maximum aggregation R = 0, and under conditions of maximum spacing (hexagonal lattice) R = 2.1491.

The use of distances from individuals to their nth nearest neighbors was discussed by Thompson (1956). The use of the distance to the second, third, etc., neighbors was cited as making it possible to detect larger scale heterogeneity than by merely using the distance to the nearest neighbor. He showed that the distribution of the distance r_n to the nth nearest neighbor is

$$P(r_n) = \frac{2\lambda^n e^{-\lambda r_n^2} r_n^{2n-1} dr_n}{(n-1)!}$$

where $\lambda = \pi m$ and m is density per unit area. If $x_n = 2\lambda r_n^2$

$$P(x_n) = \frac{e^{-x_n/2} (x_n/2)^{n-1}}{(n-1)!}$$

which is distributed as χ^2 with 2_n d.f.

For a sample size N, the statistic $N\bar{x}_n$ where $\bar{x}_n$ is the mean of the N observed values of x_n is distributed as χ^2 with 2 N_n d.f. A probability of χ^2 >0.95 indicates significant overdispersion and distances smaller than expected. A probability of χ^2 <0.05 indicates significant underdispersion.

The procedure proposed by Thompson then is to estimate $\lambda_o = \pi m_o$, where m_o is the observed density of the individuals, calculate the mean $\bar{x}_n$ of N observed quantities $2\lambda_o \bar{r}_n^{\,2}$ and compare it with the expected limits under the hypothesis of randomness.

Pielou (1959) investigated the use of point to plant distances in the study of the pattern of plant populations. She showed that if r is the distance from a random point to the plant nearest it, in a random dispersed population, and if r has the frequency function $2\lambda r e^{-\lambda r^2}$ where λ is the density in terms of number of individuals per unit radius, then taking $w = r^2$, w has the frequency function $f(w) = \lambda e^{-\lambda w}$ and $E(w) = 1/\lambda$. $E(\bar{w}) = (n-1)/n\lambda$ where n is number of distances measured. If $\lambda = \pi D$ where D is the number of individuals per unit area, then

$$E(\pi D\bar{w}) = \frac{n-1}{n} .$$

The value $\pi D\bar{w}$ Pielou called α. If α is found to be not significantly different from $\frac{n-1}{n}$, the population may be assumed random. α is larger for aggregated and smaller for regularly dispersed populations. For random populations Pielou showed that α has a frequency function

$$\frac{n^n \alpha^{n-1} e^{-n\alpha}}{\Gamma(n)}$$

and therefore $2n\alpha$ is distributed like χ^2 with 2n degrees of freedom. In a nonrandom population, this cannot be assumed, and the number of measurements must be large enough to justify that $\bar{w}$ is nearly normal.

Pielou stated that a t-test can probably safely be made if not less than 100 distances are measured in each population.

Moore (1954) derived a method similar to Pielou's using the probability of finding a plant in the annulus between radius r and $r + \delta r$ from a randomly selected point.

The importance of making all measurements from randomly selected points, when the individuals are not randomly distributed, was pointed out by Eberhardt (1967). This procedure is necessary to insure statistical independence.

Need for Uniform Granule Distribution

Several investigators have expressed the need for uniform application of granular materials and have worked to measure and describe uniformity of distribution from granular applicators.

Byass (1968) reported that the amount of herbicide deposited at any point in a field, with present application equipment, varies considerably. Typical coefficients of variation for 50 cm^2 areas were 35-40%.

Farmery (1970) observed that the effectiveness of a pesticide is dependent on the material being in the right place at the right time, and in the correct amount. He stated that broadcasting granules for weed control demands a good ground pattern at a high working rate. Because the application technique is similar to spreading fertilizer, observers tend to go by looks and assumption, but the consequences of variations in rates and patterns can be far more serious with herbicides than with fertilizers.

Holly (1970) stressed that uniform application is important. As uniformity improves, the chance of a weed seedling not being exposed to a lethal dose of herbicide is reduced. The chance of a crop plant being exposed to an overdose also decreases. Since with uniform application a margin of overdose is not needed to insure control of low spots, less herbicide is needed. And the problem of persistence is reduced since areas of high concentration are eliminated. Goehlich (1970) also stated that accurate output and distribution are necessary to maintain activity and selectivity.

Gunkel and Hosokawa (1964) commented that though very little research work specifically related to uniformity of discharge has been published, it is reasonable to assume a high correlation between pesticide effectiveness and uniformity of discharge. It was concluded by Lovely and Staniforth (1959) that although uniform distribution over the treated area is more important with herbicides than with insecticides it is still not critical. They reported similar weed control with from 5 to 50 granules per square inch. Price and Gunkel (1965) stated that due to high material cost and low application rate uniform distribution is essential. Amsden (1970) speculated on the savings, from decreased dosage rate, which could be attained by improved accuracy of metering and dispensing.

Evaluation of Applicator Performance

Most of the investigations of granular application performance have been concerned with measuring the flow over some period of time, with measuring the amount collected in some area, or with merely observing the output distribution.

Walker (1961) evaluated the distribution from a rotary knapsack granule distributor. He observed the general distribution of granules caught on a greased board when the machine was operated stationary. To evaluate the distribution under operating conditions, the granules were caught on greased 2x3 cm glass slides which were marked with a mm square grid. The granules were sized and counted with a microscope. The weight of granules collected in 6-cm-diameter containers placed across the treated area was also determined. The results were displayed graphically. Walker determined the size distribution of the 30/60 mesh granules with a microscope and the weight distribution by weighing sieved fractions.

Performance data for a granular herbicide distributor for experimental field trials were determined by Danielson and Chambers (1957). They measured the weight of granules delivered when traveling a distance of 400 ft vs speed and also weight delivered per 50 revolutions of applicator vs applicator setting. Henderson (1959) determined the output uniformity of a hand-carried precision applicator by collecting the total output of the machine for one-half minute.

Farmery (1970) measured the distribution accuracy by weighing the material caught in trays. Goehlich (1970) determined output of applicator by analog recording of the flow. He determined lateral distribution by weighing material caught in 10-cm-wide containers.

Gunkel and Hosokawa (1964) determined the fluctuation in amount of material caught in containers passing under an applicator. They found the flow rate of a typical applicator to change at least once every 0.1 sec and that while the mean flow rate remained constant the flow rate varied from 62.9 lb/acre (70.5 kg/ha) to 14 lb/acre (15.7 kg/ha). They compared applicators based on maximum and minimum flow rates and on maximum fluctuations in flow rate. Price and Gunkel (1965) investigated the distribution from a granular applicator which was subjected to shocks similar to those found in the field. Granules were collected in one-inch-square plastic containers and the data plotted and distributions visually observed.

Holzhei and Gunkel (1967) also reported on flow from a granular applicator subjected to simulated field shocks. Granules were caught in trays fastened to a belt. Each tray was divided into 14 sections to measure crosswise flow pattern. The belt speed was such that the output from three flutes passing the orifice of the applicator was caught in 25 trays. The coefficient of variation was the statistic used for comparison of the metering devices.

Reichard and Hedden (1970) investigated the variation in distribution of material dispersed from commercial and experimental granular applicators. They collected the output of applicators in 4-in.-square containers placed on a 25-ft-circumference turntable. The sample weights were plotted and fluctuations about the mean observed graphically. The coefficient of variation of sample weights varied from 7 to 70% for the applicators and conditions observed.

Coefficient of uniformity was the parameter used by Bode, Gebhardt, and Day (1966) to compare the uniformity of spray deposits. They defined coefficient of uniformity as

$$C.U. = \left[\frac{\sigma_{max} - \sigma_{observed}}{\sigma_{max}}\right] 100$$

where $\sigma_{max} = \bar{x}\sqrt{N}$

$\bar{x}$ = mean

N = sample size.

C.U. is maximum when $\sigma_{observed} = 0$, or the distribution is uniform.

Effect of Uniformity of Application

A theory on the uniformity of placement of fertilizers with respect to placing the fertilizer in bands of various widths vs applying the fertilizer broadcast was developed by DeWit (1953). He related the ratio of uptake of placed fertilizer and uptake of broadcast fertilizer to the ratio of area fertilized with placed application and area covered with broadcast application. He found the uptake ratio to be greater than the ratio of the area fertilized. No determination of the uniformity of placement within the fertilized area was made.

Whitehead, Garner, and Webb (1970) evaluated weed control effectiveness of trifluralin as a function of mixing uniformity. They expressed degree of mixing with a uniformity index equal to the coefficient of uniformity of herbicide concentrations of one-inch-square soil samples. The technique for mixing was to place treated soil in randomly assigned 0.375 in. by 2 in. by 2 in. deep slots in a placement apparatus. All other slots were filled with untreated soil. The herbicide dispersion was not varied vertically. The effects of herbicide concentration and degree of mixing were evaluated by measuring the number of grain sorghum seeds germinated, plant height, and green and dry weight of plants. Whitehead, Garner, and Webb concluded that the lower concentrations with low coefficient of variation gave control similar to that with high concentrations and high coefficient of variation and that as degree of mixing increased, for given concentration, plant growth decreased.

EXPERIMENTAL MATERIALS AND PROCEDURE

Granule Distribution Uniformity

Several granule spatial distributions were evaluated and compared using the distribution index (α). This index was computed using the method described by Pielou (1959). The granule distribution index,

$$\alpha = \pi \rho \overline{r^2}$$

where ρ = granule density,

$\overline{r^2}$ = average squared distance from random point to its nearest granule,

was based on the shortest distances from randomly located points to granules.

Distribution indices were calculated for several hexagonal lattice, square lattice, random, and aggregated distributions. A granule density of 0.10 granules/cm^2 was used. Each index was computed using 100 points randomly located in a 14 by 22 cm area. This area was randomly located on the granule distribution.

The effect of inaccurate placing of granules in hexagonal and square lattice distributions was evaluated by misplacing each granule from its desired location. The direction of misplacement was randomly selected from a uniform distribution, with limits 0 and 2π, and the distance was the absolute value of a number randomly selected from a normal distribution with mean zero and a specified standard deviation. Misplacement was increased by increasing the standard deviation.

For the aggregated distributions with circular clusters, the distance of each granule in a cluster from the loci of the cluster was determined using the above procedure. For the aggregated distributions with linear clusters, the location on the line was randomly selected from a uniform distribution, and the distance from the line was a random normal deviate selected from a distribution with mean 0 and standard deviation σ. As σ becomes larger the granule distribution whether regular or aggregated approaches randomness.

Theoretical Evaluation of Herbicide Granule Distribution

The importance of uniformity of herbicide granule distribution was evaluated under idealized conditions. It was assumed that the herbicide granules applied to the soil surface comprise a finite number of point sources of herbicide. The herbicide moves from these points by diffusion and mass flow into the surrounding soil (Mullins, 1965, and Molnau and others, 1973). The concentration gradient of herbicide in a horizontal plane about each granule is a function of soil conditions, weather conditions, depth of granule placement, herbicide properties, and time after application. The herbicide concentration gradient gives rise to a function (f(d)) which describes the phytotoxic effect in terms of the horizontal distance (d) from a granule. Assuming soil is homogeneous and isotropic in the horizontal direction, f(d) will be independent of direction.

The radius-of-influence (ROI) is defined as the maximum value of d for which weeds will be adequately controlled. The area-of-influence

(AOI) of an individual granule is then a circle, centered at the granule, with radius ROI. Weed control within the AOI will be greater than or equal to some acceptable level.

Assuming negligible interaction between AOI's, acceptable control will be obtained when granules are dispersed with a density and uniformity such that all of the area to be controlled will be under an AOI. That distribution which gives complete coverage with minimum overlap of AOI's will be most efficient and will require the minimum herbicide rate. Coverage (C) is that proportion of the surface area which is within the AOI of one or more granules.

With circular AOI's some overlap is necessary to obtain complete coverage. For regular distributions the overlap attributable to each granule may be calculated using the relationship that the area common to two circles with radii ROI and centers distance d_1 apart is

$$2\ (\mathrm{ROI})^2\ (\theta - \sin\theta\cos\theta)$$

where $\theta = \cos^{-1} \frac{d_1}{2}$ (ROI). (Garwood, 1947).

The overlap for each granule is one-half the sum of the areas that granule has in common with other granules.

For other than regular distributions, computation of coverage and overlap becomes complex. Therefore coverage was estimated by the proportion of randomly located points (the same points used to calculate α) which were less than 1 ROI from a granule. Similarly, the overlap (0), defined as the area equivalent to $\Sigma(n-1)A_n$, where A_n is the portion of the surface area which is in the AOI of n granules, was estimated by

$\Sigma(n-1)P_n$, where P_n is the number of points less than 1 ROI from n granules.

Distribution efficiency (E), a measure of the herbicide effectively used compared to the total herbicide applied, was estimated by

$$E = \frac{C}{C+O} .$$

The distribution adequacy (A), defined as the product of coverage and efficiency, was computed to more adequately describe the acceptability of the distribution.

$$A = C\ E = \frac{C^2}{C+O} .$$

For a granule distribution to have a high distribution adequacy it must have both a high efficiency and a high coverage.

Coverage, distribution efficiency, and distribution adequacy were calculated for several granule distributions.

Plants, Herbicides and Soils

Millet (Setaria italica (L.) Beauv.) and velvetleaf (Abutilon theophrasti) were the indicator plants used to evaluate control from granules impregnated with 2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide (alachlor) and 2-chloro-4(ethylamino)-6-(isopropylamino)-S-triazine (atrazine). Attapulgus LVM 8/10, 8/15 and 24/48 mesh granules were used. The plants were grown in soils from the Clarion-Nicollet-Webster soil association. Properties and characteristics of the plants, granules, herbicides and soils are given in Appendix 1.

Herbicide Granule Area-of-Influence

The effects of depth of granule placement, depth of weed seeds, soil moisture content, and simulated rain on the level of control and magnitude of the area controlled by individual granules were investigated in greenhouse and field tests.

Seeds were planted at one centimeter intervals along each ray of a 6-pointed star with the herbicide granule placed at the center. When the herbicide effect was apparent, the condition of each plant was rated. The rating schemes used are described in Appendix 2. The ratings for the six locations equidistant from the granules were averaged. The average values were analyzed with an analysis of variance (Service, 1972) to determine significant treatment effects. The relationship of control to distance from granule was evaluated using nonlinear regression analysis (Atkinson, 1966). The radius-of-influence (ROI) was determined from this relationship.

Greenhouse ROI tests

In greenhouse test ROI 1, moisture, seed depth, and rain treatments were assigned to pans, and granule depth to stars within a pan. The initial moisture contents were 17 and 23%. Millet seeds were planted at 1/4, 1, and 2 cm depths with 8/10 mesh alachlor granules placed on the surface or 1 or 2 cm deep. A no-granule check was included. One centimeter of water was applied as simulated rain either right after planting or 2 or 5 days after planting. Black loam soil was used in this test and the planting pattern, with 2 seeds per location, was as shown in Figure A2-1. Each treatment was replicated 3 times.

Effects of soil moisture, simulated rainfall, seed depth, and granule depth were investigated in greenhouse test ROI 2. Brown loam soil was used in this test and was at 13% moisture when the seeds were planted. Immediately after planting water was added by subirrigation to one-half of the pans, raising the moisture content to 23%. Simulated rain treatments of 1 cm were applied either the day after planting or the day after plants began to emerge. A no-rain treatment was included. Those pans which did not receive a rain treatment were subirrigated with an equal amount of water. Millet was planted either 1 or 2 cm deep and 8/10 mesh alachlor granules were placed on the surface, or 1 or 2 cm deep. A no-granule check was included in each pan. The planting pattern, with 2 seeds per location (Figure A2-1) was used and each treatment was replicated 3 times.

Millet and velvetleaf were planted in brown loam soil 1 cm deep in the star configuration shown in Figure A2-2 for greenhouse test ROI 3. The millet was planted with 2 seeds per location. In this test each treatment was replicated 8 times. The variables investigated were initial soil moisture (8 and 15%), granule depth (on the surface or 1 cm deep, with a no-granule check), and method of moisture addition (2 cm simulated rain or 2 cm subirrigation). Alachlor granules (8/10 mesh) were used with the millet and 8/15 mesh atrazine granules with the velvetleaf.

Granules from a commercial formulation (24/48 mesh) of alachlor were used in greenhouse test ROI 4. Millet seeds were planted 1 cm deep with 2 seeds per location in pattern shown in Figure A2-1.

The granules were placed on the surface. Brown loam soil was used and was initially at 15% moisture. Simulated rain was applied either the day after planting or the day after the plants began to emerge. Those pans not receiving simulated rain were subirrigated.

Field ROI test

Atrazine granules (8/10 mesh) and alachlor granules (8/15 mesh) were placed at the center of stars of velvetleaf and millet, respectively. The seeds were planted 1, 2, and 3 cm deep in black loam soil with granules placed on surface or 1, 2, or 3 cm deep. A no-granule check at each seed depth was included. Rainfall and temperature data for the field test are given in Table A2-1.

Interaction of Herbicide Granule Areas-of-Influence

Two greenhouse tests and a field test were performed to determine whether the area controlled by two granules would be a function of the distance between the granules and whether at a spacing of near two ROI the combined area-of-control would be greater than twice the AOI of an individual granule.

Greenhouse AOI interaction tests

Two alachlor granules (8/10 mesh) were placed on the soil surface at 0, 1, 3, 5, 7, and 9 cm spacings in greenhouse AOI interaction test 1. A one-granule and a no-granule check were included. Three water addition treatments were used: simulated rain applied either one day after planting or one day after plants began to emerge or no rain.

Millet seeds were planted one cm deep in a 1 cm square lattice with two seeds planted per location. Brown loam soil at 14% initial soil moisture was used.

Greenhouse AOI interaction test 2 differed from test 1 only in that the seeds were planted by mixing 3 gm of seeds in the top 1 cm (550 grams) of soil before the soil was added to the pan.

The area of control in both tests was determined by placing a glass plate on the pan and tracing the outline of the area controlled. This outline was then traced onto a paper on which points in a 1 cm lattice had been printed. The area of control was measured by counting the number of points in the area. The data were analyzed with a regression analysis of area vs distance between granules.

Field AOI interaction test

Alachlor granules (8/10 mesh) were placed on the soil surface at 0, 2, 4, 6, 8, and 10 cm spacings. A 1 granule and no granule check were included. Millet seeds were planted 1 cm deep in a 2 cm square grid. After the control was apparent, each plant was rated and the control versus distance between granules was analyzed.

Control Versus Granule Distribution

The relationships between uniformity of herbicide granule distribution and control and between predicted and experimental control of granule distributions were investigated.

Greenhouse granule distribution tests

Alachlor granules (8/10 mesh) distributed at 0.012 and 0.024 granules/cm^2 in random and hexagonal lattice distributions were investigated in greenhouse granule distribution test 1. A template (Figure A2-3) was used to aid in positioning the granules. The millet seeds for the millet/alachlor evaluation were planted in a 1 cm square lattice. The velvetleaf seeds for the velvetleaf/atrazine test were planted in a 2 cm square lattice. All seeds were planted 1 cm deep. Alachlor granules used were 8/10 mesh and 8/15 mesh atrazine granules were used. The variables investigated were granule depth (on the surface or 1 cm deep), initial moisture (8 or 15%) and simulated rain (the day after planting or none). After herbicide effect was apparent, the control of each plant was rated. A position locator (Appendix 3) facilitated recording of the ratings.

In greenhouse small granule distribution test 2, commercial (24/48 mesh) alachlor granules were applied in a 2 cm square lattice and with a commercial fluted wheel metering device and spreader. The rates were 0.47 granules/cm^2 or 0.56 kg active ingredient/ha for the granules applied with the applicator and 0.25 granules/cm^2 or 0.30 kg active ingredient/ha for the placed granules. Millet seeds, at the rate of 2 per cm^2, were planted by mixing with 150 gm of soil, spreading uniformly in the pan and covering with 3/4 cm of soil. The soil was initially at 15% moisture and simulated rain treatments were applied either the day after planting or when the plants began to emerge. The granule locations were recorded with the position locator. To aid in seeing the granules, a fluorescent water color was sprayed on the granules before application. The granules were located under an ultraviolet lamp. After control was apparent, the locations of surviving plants were recorded with the position locator.

Field granule distribution test

Alachlor granules (8/10 mesh) and atrazine granules (8/15 mesh) were distributed in hexagonal lattice, square lattice and random distributions in the field granule distribution test. Granules were distributed at four densities (0.0045, 0.0080, 0.0180, and 0.0722 granules/cm) in three combinations of seed and granule depth. Granules were placed on the surface or 1 cm deep with seeds planted 1 cm deep. When seeds were planted at 2 cm, granules were placed 1 cm deep. After control was apparent each plant was rated.

RESULTS AND DISCUSSION

Granule Distribution Uniformity

The lowest distribution index was obtained for the hexagonal lattice distribution indicating that this distribution was most uniform. This agreed with Clark and Evans (1954) and Meschkowski (1966) who showed that the hexagonal lattice distribution is the most efficient spatial distribution of circular areas. The distribution index increased as the distributions became less regular. For a random distribution α is approximately double that for the regular lattice distributions.

Distribution indices for several granule distributions are given in Table 1. (Examples of the granule distributions are given in Appendix 4 along with a set of random points used in calculation of α.)

Theoretical Effect of Herbicide Granule Distribution

The herbicide granule density (ρ; denoted by RHO in the figures) needed for acceptable control is linearly proportional to α (Figure 1). The rate of increase decreases as the area controlled by each granule increases.

The least squares fit of $\rho = \beta_o + \beta_1 \alpha$ to the data gave the following estimated relationships for conditions with ROI's of 2.0, 3.0 and 4.0 cm respectively.

$$\rho = -\ 0.032 + 0.242\alpha$$
$$\rho = -\ 0.021 + 0.110\alpha$$
$$\rho = -\ 0.011 + 0.072\alpha$$

These relationships along with their 95% confidence limits are also shown

Table 1. Distribution indices for several granule distributions.

Distribution	Standard deviation of misplacement (σ) cm	α[a]
Hexagonal lattice	0	0.49
	0.5	0.52
	1.5	0.65
	2.5	0.80
Square lattice	0	0.51
	0.5	0.54
	1.5	0.75
	2.5	0.82
Random		1.02
Aggregated		
Circular clusters	1.0	5.05
	2.0	2.97
	3.0	1.92
Linear clusters	1.0	1.72
	2.0	1.04
	3.0	0.89
LSD t_{o5} for granule distribution =	0.15	

[a]Values are means of 4 observations.

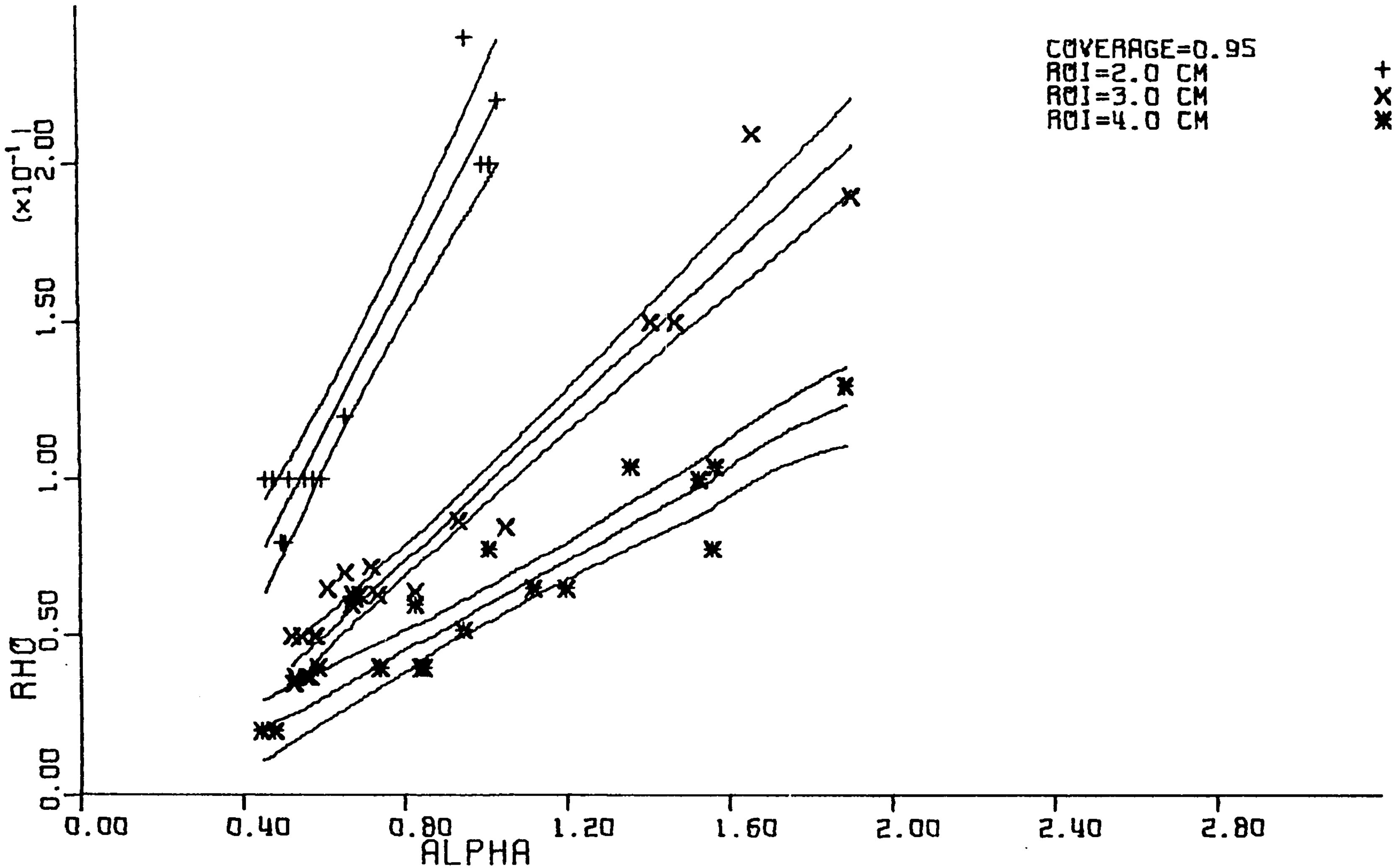

Figure 1. Granule density (ρ) needed for 0.95 coverage as function of ROI and distribution index (α).

in Figure 1. When α is a minimum (about 0.5), ρ is inversely proportional to the area controlled by each granule.

The amount of herbicide required for control with a random distribution is approximately double that needed for a hexagonal lattice distribution. Since commercial applicators tend to apply an aggregated distribution, the herbicide rate applied with them must be in excess of twice the amount necessary for control when applied in a hexagonal lattice distribution.

The responses of coverage, distribution efficiency, and distribution adequacy to α are shown in Figures 2 through 10 for combinations of ROI (1, 2, and 3 cm) with granule density (0.02, 0.06, and 0.10 granules/cm^2).

The greatest response of coverage to α is shown for combinations of ROI and ρ for which coverage at low α is high without excessive overlap. This is shown in Figure 3 for an ROI of 2.0 cm with densities of 0.06 and 0.10 granules/cm^2 and in Figure 4 for an ROI of 3.0 cm with ρ of 0.02 granules/cm^2. When coverage is low (Figure 2) or high with excessive overlap (Figure 4; ROI = 3.0 cm, ρ = 0.10 granules/cm^2), uniformity of distribution has little effect on coverage.

Distribution efficiency decreases as α increases for distributions where coverage is high without excessive overlap (Figure 6; ROI = 2.0 cm, ρ = 0.06 and 0.10 granules/cm^2). When coverage is low, efficiency is high (Figure 5) and does not respond to α. When coverage is high with excessive overlap, efficiency is low (Figure 7; ROI = 3.0 cm, ρ = 0.10 granules/cm^2) and also does not respond to α.

Distribution adequacy, the product of coverage and distribution

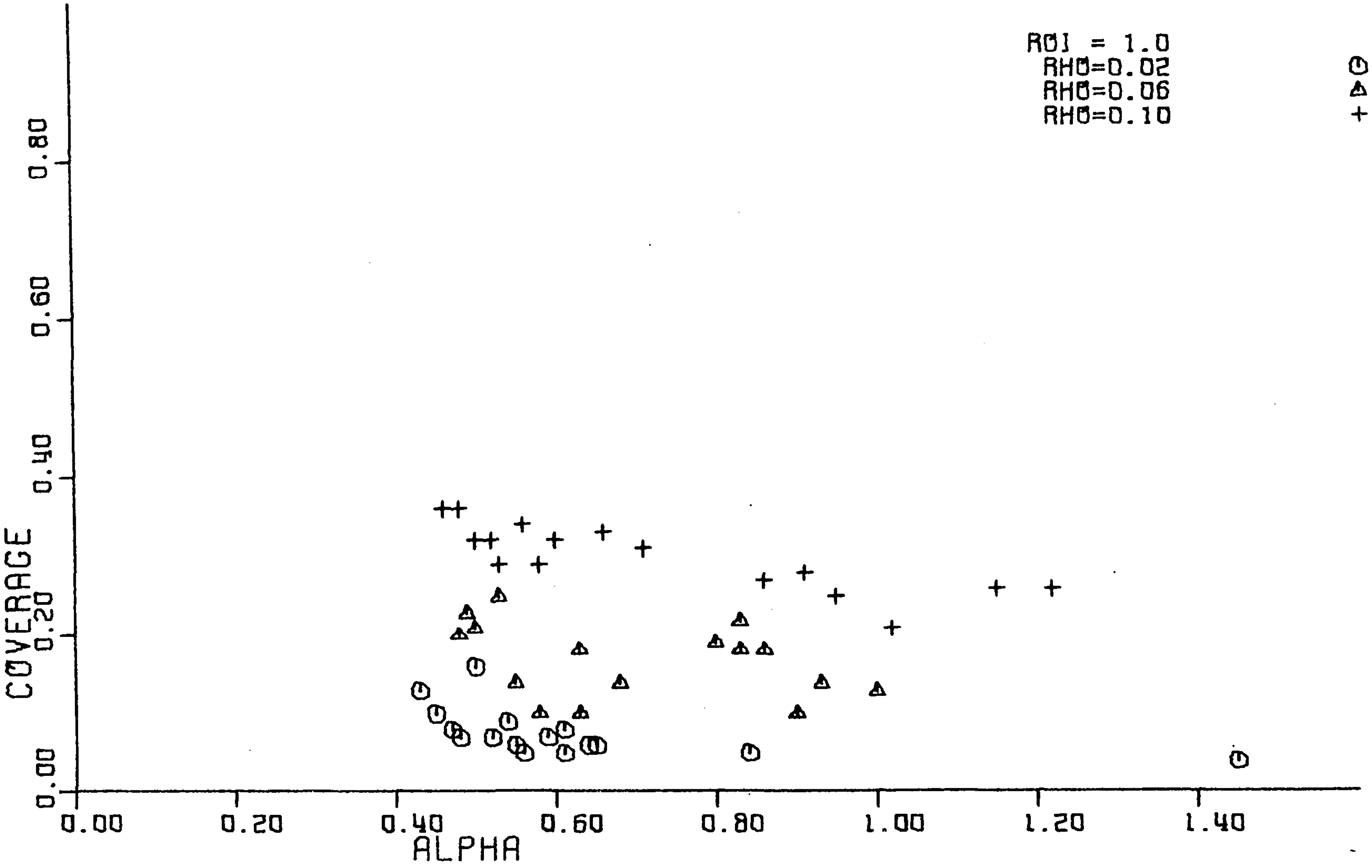

Figure 2. Coverage versus distribution index for 3 granule densities at ROI = 1.0.

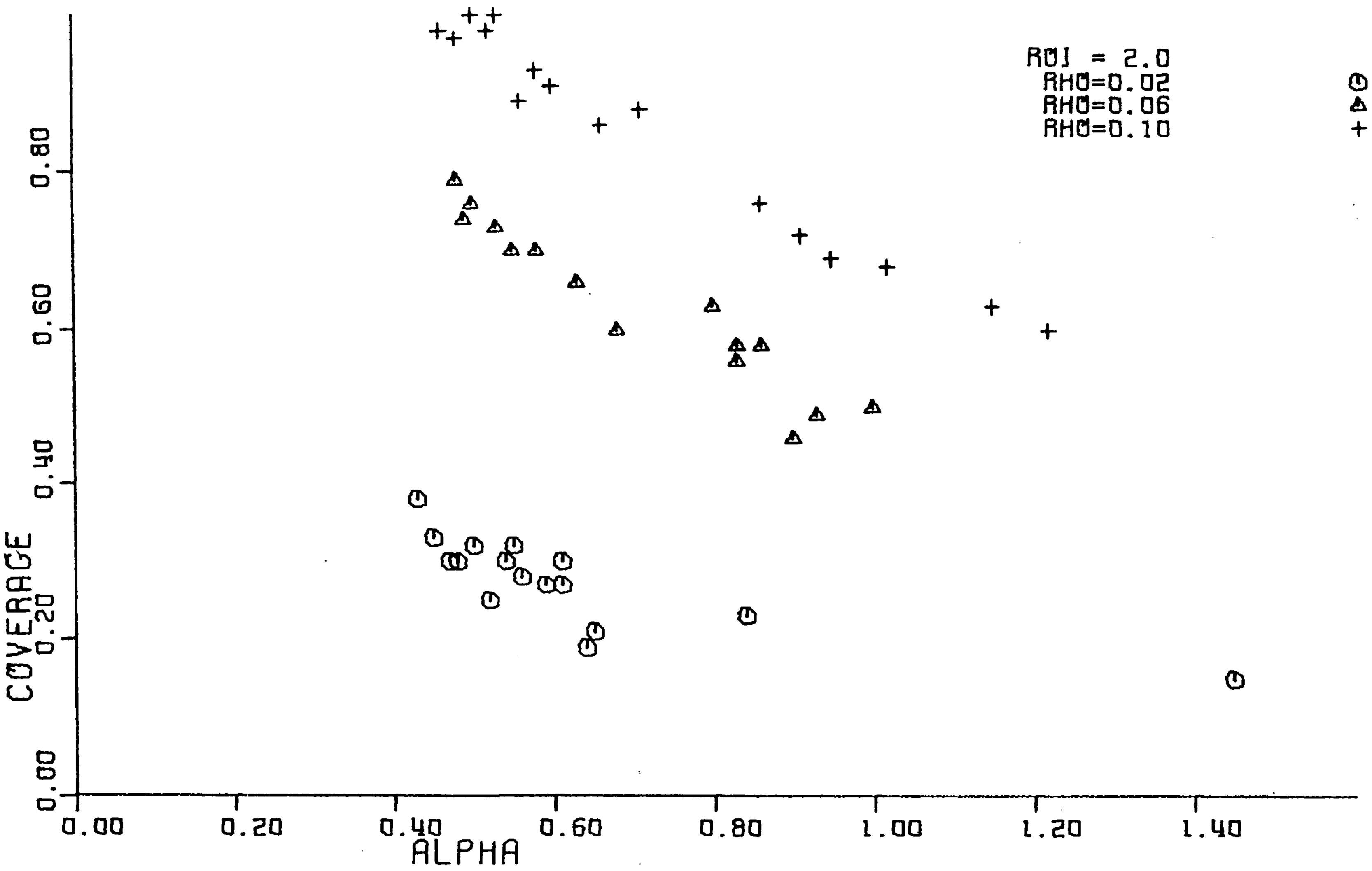

Figure 3. Coverage versus distribution index for 3 granule densities at ROI = 2.0.

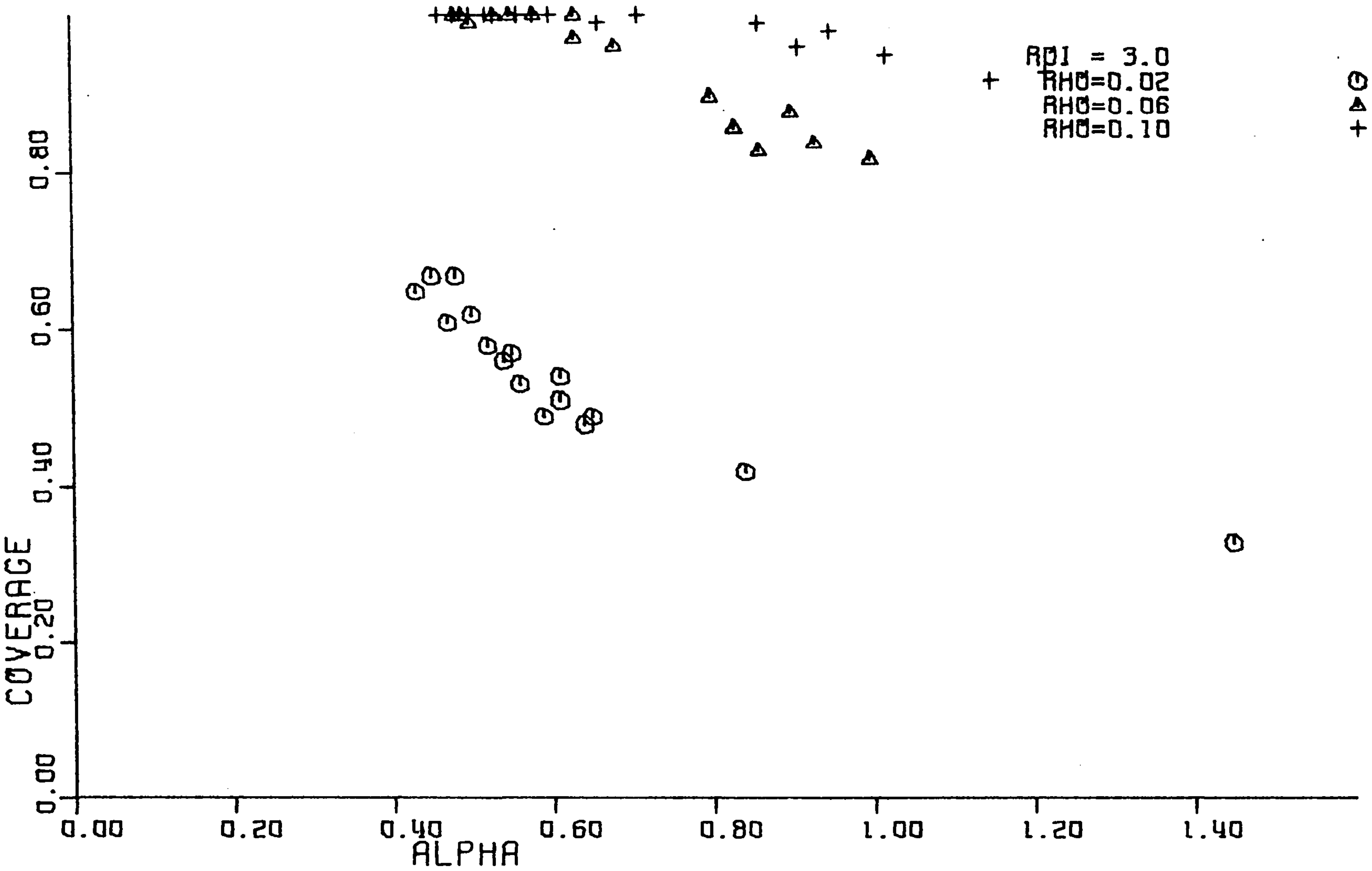

Figure 4. Coverage versus distribution index for 3 granule densities at ROI = 3.0.

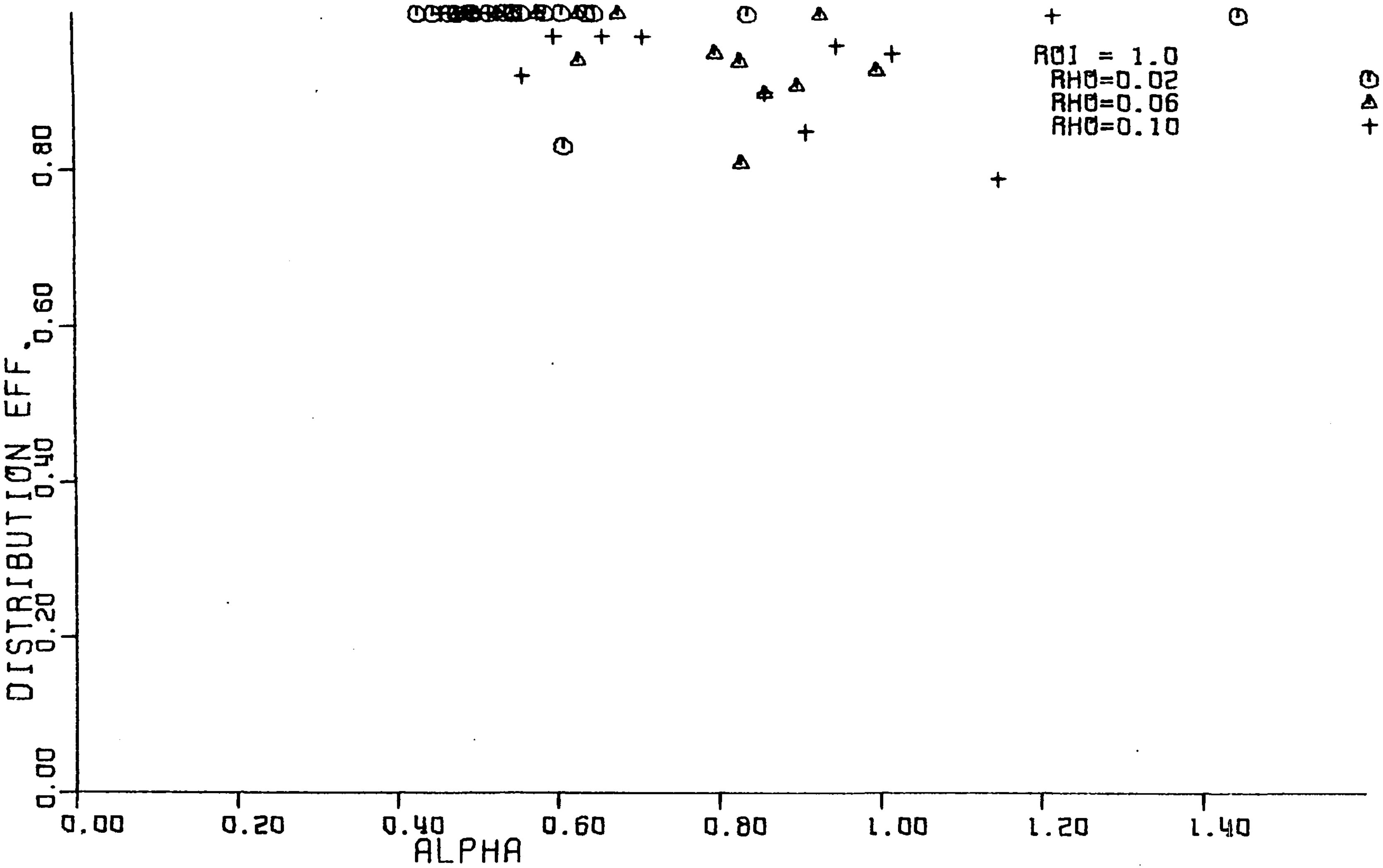

Figure 5. Distribution efficiency versus distribution index for 3 granule densities at ROI = 1.0.

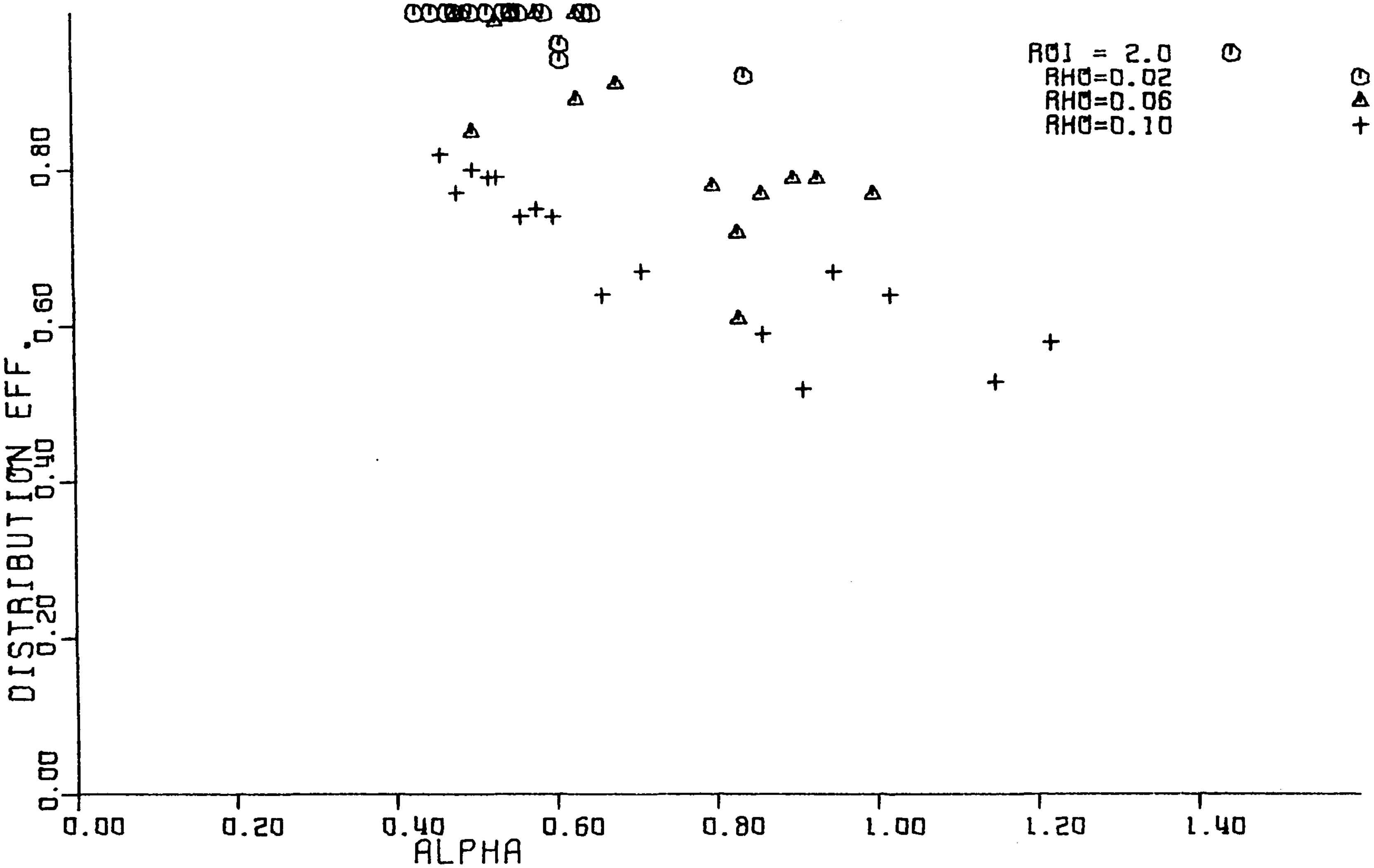

Figure 6. Distribution efficiency versus distribution index for 3 granule densities at ROI = 2.0.

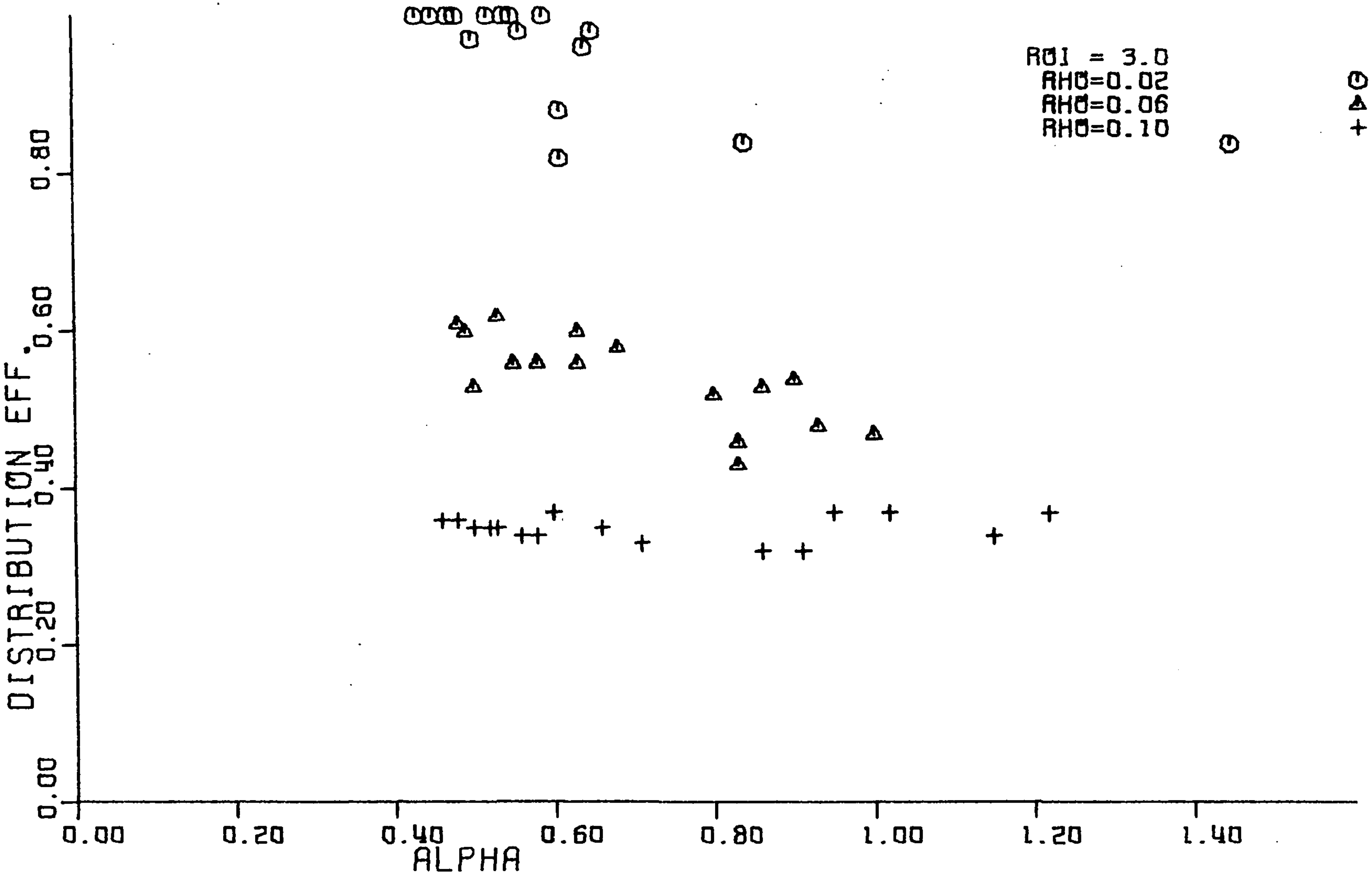

Figure 7. Distribution efficiency versus distribution index for 3 granule densities at ROI = 3.0.

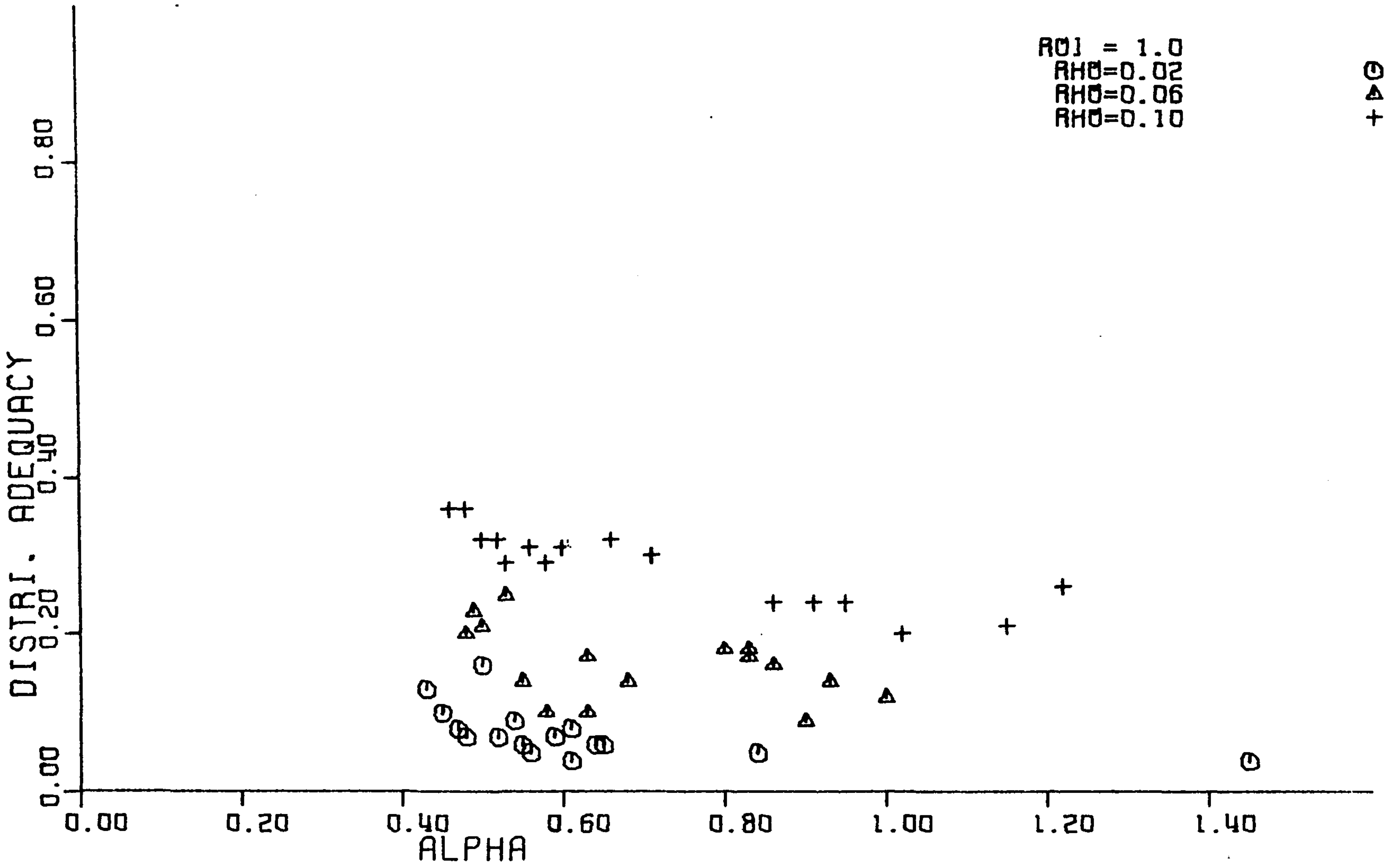

Figure 8. Distribution adequacy versus distribution index for 3 granule densities at ROI = 1.0.

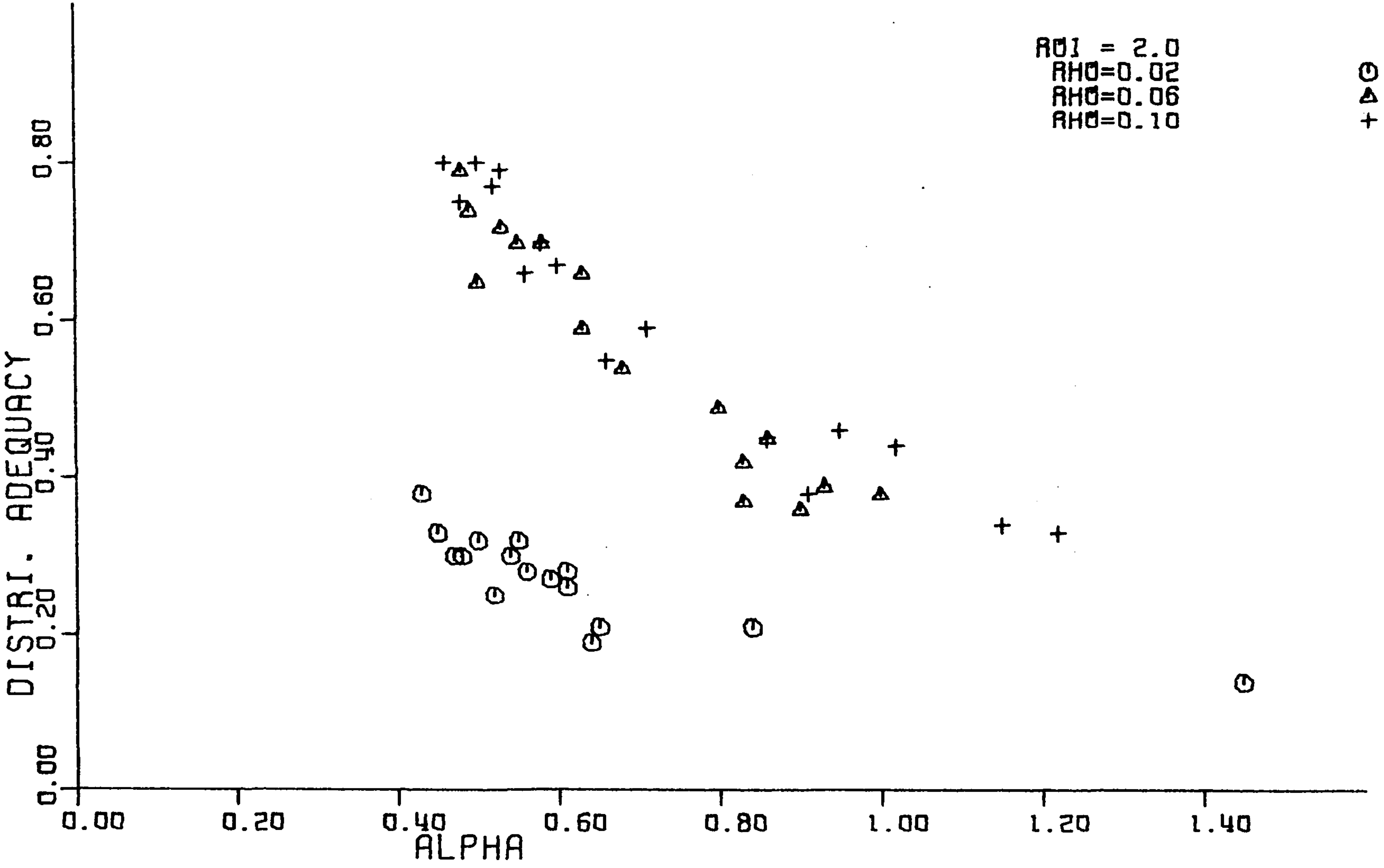

Figure 9. Distribution adequacy versus distribution index for 3 granule densities at ROI = 2.0.

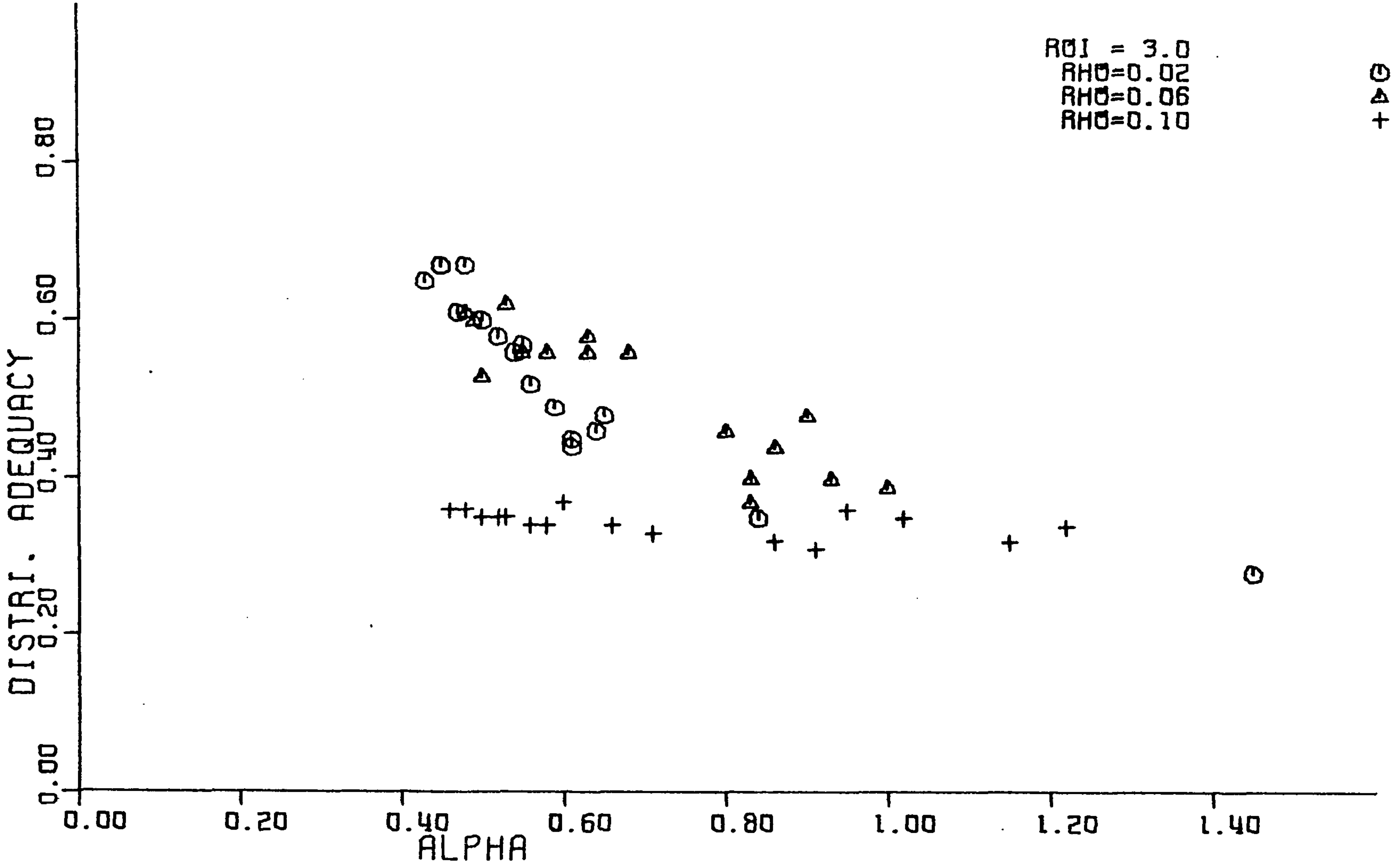

Figure 10. Distribution adequacy versus distribution index for 3 granule densities at ROI = 3.0.

efficiency, responds similarly. Distribution adequacy decreases rapidly with increase in α for combinations of ROI and ρ for which coverage for a uniform distribution is high without excessive overlap (Figure 9; ROI = 2.0 cm with ρ = 0.06 and 0.10 granules/cm^2 and Figure 10; ROI = 3.0 cm with ρ = 0.02 granules/cm^2). For other combinations of ROI and ρ distribution, uniformity had little effect on distribution adequacy.

The response to uniform granule distribution is shown clearly in Figures 3, 6, and 9 for an ROI of 2.0 cm and a granule density of 0.10 granules/cm^2. As α increases from 0.5 to 1.2, coverage decreases from 1.0 to 0.6, distribution efficiency from 0.8 to 0.55 and distribution adequacy from 0.8 to 0.35. (The maximum theoretical distribution efficiency and distribution adequacy are both 0.83.)

Individual Granule Control

Granule depth, seed depth, soil moisture content, and method of moisture addition affected the average control of plants, planted in a star pattern, by an individual granule.

Table 2 gives the average control of millet with alachlor for the levels of variables tested in greenhouse test ROI 1. Control was better at the high moisture content, increased with increasing seed depth, and decreased with increasing granule depth. The length of time between planting and rain had no significant effect on control. This was probably because an equivalent amount of water was added by subirrigation to the pans not receiving rain to prevent nonuniform stress on the

Table 2. Average control of millet with alachlor for levels of variables tested in greenhouse test ROI 1.

Variable	Level	Control
Soil moisture	17%	0.59
	23%	0.74
Seed depth	1/4 cm	0.60
	1 cm	0.69
	2 cm	0.72
Time between planting and rain	1 hr	0.71
	2 days	0.64
	5 days	0.65
Granule depth	0 cm	0.85
	1 cm	0.66
	2 cm	0.49

LSD t_{o5} for soil moisture = 0.07

LSD t_{o5} for seed depth = 0.08

LSD t_{o5} for time between planting and rain = 0.08

LSD t_{o5} for granule depth = 0.05

seedlings.

Interactions of granule depth with initial soil moisture, with seed depth, and with length of time between planting and rain affected control. Control was best when the granule was placed above the seeds and decreased as the depth of the seeds relative to the granule decreased (Table 3). The effect of granule depth increased as the time between planting and rain increased (Table 4).

The initial soil moisture was less important when the granules were placed on the surface than when they were 1 or 2 cm deep (Table 5).

Table 3. Effect of seed depth and granule depth on average control of millet with alachlor for greenhouse test ROI 1.

Seed depth cm	Granule depth cm	Control
1/4	0	0.79
	1	0.55
	2	0.45
1	0	0.95
	1	0.66
	2	0.46
2	0	0.81
	1	0.77
	2	0.57

LSD t_{05} for granule depth at given seed depth = 0.09

LSD t_{05} for seed depth at given granule depth = 0.11

Table 4. Effect of granule depth and time between planting and rain on average control of millet with alachlor for greenhouse test ROI 1.

Time between planting and rain	Granule depth cm	Control
1 hr	0	0.82
	1	0.67
	2	0.64
2 days	0	0.82
	1	0.66
	2	0.45
5 days	0	0.91
	1	0.64
	2	0.39

LSD t_{05} for time between planting and rain at given granule depth = 0.11
LSD t_{05} for granule depth at given time between planting and rain = 0.09

Table 5. Effect of soil moisture and granule depth on average control of millet with alachlor for greenhouse test ROI 1.

Soil moisture %	Granule depth cm	Control
17	0	0.81
	1	0.55
	2	0.41
23	0	0.89
	1	0.77
	2	0.57

LSD t_{05} for granule depth at given initial moisture = 0.07

LSD t_{05} for initial moisture at given granule depth = 0.09

Control decreased more rapidly with depth at the low soil moisture.

Table 6 gives the average control of millet with alachlor for the levels of variables tested in greenhouse test ROI 2. Control was better at the 23% moisture content than at the 13% moisture content and also better at the 2 cm seed depth than at the 1 cm depth. Granules on the surface gave better control than those placed 1 or 2 cm deep. Simulated rain improved control over the no rain treatment, but the time of rain application was not important.

Interactions of initial soil moisture with granule depth, time between planting and rain with granule depth, and soil moisture with rain affected control. Control decreased more rapidly with granule depth for the 13% than the 23% soil moisture (Table 7). Control when the granules were placed on the surface was dependent on whether or not rain was applied (Table 8). Control when the granules were 1 or 2 cm deep was

Table 6. Average control of millet with alachlor for levels of variables tested in greenhouse test ROI 2.

Variable	Level	Control
Soil moisture	13%	0.50
	23%	0.66
Time between planting and rain	1 day	0.61
	4 days	0.61
	no rain	0.53
Seed depth	1 cm	0.56
	2 cm	0.61
Granule depth	0	0.80
	1 cm	0.52
	2 cm	0.42

LSD t_{05} for soil moisture = 0.04
LSD t_{05} for time between planting and rain = 0.04
LSD t_{05} for seed depth = 0.04
LSD t_{05} for granule depth = 0.05

Table 7. Effect of soil moisture content and granule depth on average control of millet with alachlor for greenhouse test ROI 2.

Soil moisture %	Granule depth cm	Control
13	0	0.76
	1	0.42
	2	0.32
23	0	0.85
	1	0.62
	2	0.52

LSD t_{05} for granule depth at given soil moisture = 0.07
LSD t_{05} for soil moisture at given granule depth = 0.07

Table 8. Effect of granule depth and time between planting and rain on average control of millet with alachlor for greenhouse test ROI 2.

Time between planting and rain	Granule depth cm	Control
1 day	0	0.92
	1	0.53
	2	0.39
4 days	0	0.88
	1	0.53
	2	0.42
No rain	0	0.62
	1	0.51
	2	0.45

LSD t_{05} for granule depth at given time between planting and rain = 0.08
LSD t_{05} for time between planting and rain at given granule depth = 0.08

independent of rain. At 13% soil moisture, control was best when simulated rain was applied 4 days after planting (Table 9). At 23% soil moisture, however, the best control was obtained when rain was applied 1 day after planting.

Better control of millet with alachlor was obtained at the 15% than at the 8% soil moisture in greenhouse test ROI 3 (Table 10). Control was also better when the granules were placed on the surface than when they were 1 cm deep. There was little difference in control due to granule depth at the 15% moisture content (Table 11). However, at the 8% soil moisture content, control was better when the granules were on the surface than when they were 1 cm deep. Control was higher for the surface-placed granules when simulated rain was applied (Table 12). However, when the

Table 9. Effect of time between planting and rain on average control of millet with alachlor for greenhouse test ROI 2.

Soil moisture %	Time between planting and rain days	Control
13	1	0.50
	4	0.56
	no rain	0.45
23	1	0.73
	4	0.66
	no rain	0.61

LSD t_{o5} for soil moisture at given time between planting and rain = 0.08

LSD t_{o5} for time between planting and rain at given soil moisture = 0.08

Table 10. Average control of millet with alachlor for levels of variables tested in greenhouse test ROI 3.

Variable	Level	Control
Soil moisture	8%	0.54
	15%	0.81
Granule depth	0 cm	0.75
	1 cm	0.60
Method of moisture addition	subirrigation	0.67
	simulated rain	0.69

LSD t_{o5} for soil moisture = 0.04

LSD t_{o5} for granule depth = 0.04

LSD t_{o5} for method of moisture addition = 0.04

Table 11. Effect of granule depth and soil moisture on average control of millet with alachlor for greenhouse test ROI 3.

Soil moisture %	Granule depth cm	Control
8	0	0.66
	1	0.43
15	0	0.83
	1	0.78

LSD t_{05} for granule depth at given soil moisture = 0.05

LSD t_{05} for soil moisture at given granule depth = 0.05

Table 12. Effect of granule depth and method of moisture addition on average control of millet with alachlor for greenhouse test ROI 3.

Granule depth cm	Method of moisture addition	Control
0	subirrigation	0.71
	simulated rain	0.78
1	subirrigation	0.62
	simulated rain	0.59

LSD t_{05} for granule depth at given method of moisture addition = 0.05

LSD t_{05} for method of moisture addition at given granule depth = 0.05

granules were 1 cm deep, method of moisture addition had little effect.

Control of velvetleaf with atrazine granules in greenhouse test ROI 3 was lower than control of millet with alachlor in the other greenhouse ROI tests. Neither soil moisture content, granule depth, nor method of moisture addition affected control (Table 13). There were, however, interactions of rain with soil moisture content and with granule depth. At 8% soil moisture, better control was obtained with subirrigation than with simulated rain, while at 15% moisture the opposite was true (Table 14). Control was better with simulated rain when granules were on the surface, but when granules were placed 1 cm deep, control was better with subirrigation (Table 15).

The three-way interaction of soil moisture, granule depth and method of moisture addition also affected control (Table 16). The best average control, 0.45, was obtained with low soil moisture, with granule 1 cm deep and with moisture added by subirrigation. The poorest control, 0.20, was with low soil moisture with granule 1 cm deep, but with moisture added by simulated rain.

Dry conditions following planting of seeds and placement of granules contributed to the very poor control of velvetleaf with atrazine in the field tests. (Rainfall and temperature data during the field tests are given in Table A2-1.) Control of millet with alachlor was also lower and more variable than in greenhouse tests. This was partly because the soil moisture content was nonuniform. No significant effect of granule depth or seed depth on control of millet with alachlor was indicated.

Table 13. Average control of velvetleaf with atrazine for levels of variables tested in greenhouse test ROI 3.

Variable	Level	Control
Soil moisture	8%	0.30
	15%	0.26
Granule depth	0 cm	0.28
	1 cm	0.29
Method of moisture addition	subirrigation	0.29
	simulated rain	0.28

LSD t_{05} for soil moisture = 0.07
LSD t_{05} for granule depth = 0.06
LSD t_{05} for method of moisture addition = 0.07

Table 14. Effect of soil moisture and method of moisture addition on average control of velvetleaf with atrazine for greenhouse test ROI 3.

Soil moisture %	Method of moisture addition	Control
8	subirrigation	0.35
	simulated rain	0.26
15	subirrigation	0.23
	simulated rain	0.29

LSD t_{05} for method of moisture addition at given soil moisture = 0.10

LSD t_{05} for soil moisture at given method of moisture addition = 0.10

Table 15. Effect of granule depth and method of moisture addition on average control of velvetleaf with atrazine for greenhouse test ROI 3.

Granule depth cm	Method of moisture addition	Control
0	subirrigation	0.23
	simulated rain	0.32
1	subirrigation	0.35
	simulated rain	0.23

LSD t_{05} for granule depth at given method of moisture addition = 0.08

LSD t_{05} for method of moisture addition at given granule depth = 0.09

Table 16. Effect of soil moisture, granule depth, and method of moisture addition on average control of velvetleaf with atrazine for greenhouse test ROI 3.

Soil moisture %	Granule depth cm	Method of moisture addition	Control
8	0	subirrigation	0.24
		simulated rain	0.33
	1	subirrigation	0.45
		simulated rain	0.20
15	0	subirrigation	0.22
		simulated rain	0.32
	1	subirrigation	0.25
		simulated rain	0.26

(The results of an analysis of the check stars of greenhouse test ROI 3 to evaluate the effects of rain and soil moisture on millet and velvetleaf emergence are given in Appendix 1.)

Control Versus Distance from Granule

Control of millet with alachlor decreased with the distance of the plant from the herbicide granule. The rate of decrease was dependent upon soil moisture, granule depth, and time between planting and rain. The interactions of soil moisture with method of moisture addition, seed depth with granule depth, and soil moisture with the time between planting and rain also affected the rate of decrease in control with distance from granule.

In greenhouse test ROI 1 control decreased less with distance for the soil with 23% moisture content than for that with 17% moisture content (Table 17). Control decreased more rapidly with distance when the granule was placed 1 or 2 cm deep than when placed on the surface (Table 18). When the granule was at or above the seed depth, control decreased less rapidly with distance than when the granule was placed below the seeds (Table 19). Control decreased less rapidly with distance when soil moisture was 23% and rain was applied 1 hr after planting than it did for the other combinations of soil moisture and rain (Table 20).

In greenhouse test ROI 2, soil moisture, time between planting and rain, and depth of granule placement all affected the decrease in control of millet with alachlor, with distance from the herbicide

Table 17. Effect of soil moisture and distance from granule on control of millet with alachlor for greenhouse test ROI 1.

Soil moisture %	Distance from granule cm	Control
17	1	0.83
	2	0.62
	3	0.52
	4	0.39
23	1	0.90
	2	0.82
	3	0.69
	4	0.56

Table 18. Effect of granule depth and distance from granule on control of millet with alachlor for greenhouse test ROI 1.

Granule depth cm	Distance from granule cm	Control
0	1	0.96
	2	0.93
	3	0.83
	4	0.68
1	1	0.91
	2	0.71
	3	0.58
	4	0.43
2	1	0.73
	2	0.51
	3	0.41
	4	0.32

Table 19. Effect of seed depth, granule depth and distance from granule on control of millet with alachlor for greenhouse test ROI 1.

Seed depth cm	Granule depth cm	Distance cm	Control
1/4	0	1	0.98
		2	0.93
		3	0.79
		4	0.46
	1	1	0.86
		2	0.60
		3	0.46
		4	0.27
	2	1	0.64
		2	0.48
		3	0.37
		4	0.30
1	0	1	1.00
		2	1.00
		3	0.95
		4	0.86
	1	1	0.95
		2	0.72
		3	0.52
		4	0.44
	2	1	0.72
		2	0.47
		3	0.38
		4	0.26
2	0	1	0.90
		2	0.87
		3	0.76
		4	0.72
	1	1	0.93
		2	0.80
		3	0.76
		4	0.59
	2	1	0.83
		2	0.59
		3	0.47
		4	0.38

Table 20. Effect of soil moisture, time between planting and rain, and distance on control of millet with alachlor for greenhouse test ROI 1.

Soil moisture %	Time between planting and rain	Distance cm	Control
17	1 hr	1	0.88
		2	0.67
		3	0.51
		4	0.38
	2 days	1	0.81
		2	0.57
		3	0.45
		4	0.34
	5 days	1	0.81
		2	0.62
		3	0.60
		4	0.46
23	1 hr	1	0.94
		2	0.89
		3	0.74
		4	0.68
	2 days	1	0.90
		2	0.84
		3	0.72
		4	0.51
	5 days	1	0.87
		2	0.73
		3	0.62
		4	0.50

granule. Control decreased less rapidly with distance with the 23% than with the 13% soil moisture (Table 21). Decrease in control with distance was also less rapid when simulated rain was applied than with no rain (Table 22). Control decreased more rapidly with distance as the depth of granule placement increased (Table 23).

Control decreased more slowly with distance from the granule for the 15% soil moisture than for the 8% soil moisture in greenhouse test ROI 3 (Table 24). Control also decreased more slowly with distance when the granule was placed on the surface than when placed 1 cm deep (Table 25).

The decrease in control of velvetleaf with atrazine as distance from the granule increased was affected by soil moisture and by method of moisture addition. Control was higher near the granule but decreased more rapidly with distance for the 15% than for the 8% soil moisture (Table 26). Control near the granule was higher with simulated rain than with subirrigation but decreased more rapidly as distance increased (Table 27). The interactions of soil

Table 21. Effect of soil moisture and distance from granule on control of millet with alachlor for greenhouse test ROI 2.

Soil moisture %	Distance from granule cm	Control
13	1	0.90
	2	0.52
	3	0.36
	4	0.22
23	1	0.94
	2	0.75
	3	0.56
	4	0.40

Table 22. Effect of time between planting and rain and distance from granule on control of millet with alachlor for greenhouse test ROI 2.

Time between planting and rain days	Distance from granule cm	Control
1	1	0.92
	2	0.66
	3	0.51
	4	0.37
4	1	0.93
	2	0.63
	3	0.52
	4	0.34
No rain	1	0.91
	2	0.62
	3	0.36
	4	0.22

Table 23. Effect of granule depth and distance from granule on control of millet with alachlor for greenhouse test ROI 2.

Granule depth cm	Distance from granule cm	Control
0	1	1.00
	2	0.90
	3	0.77
	4	0.56
1	1	0.95
	2	0.58
	3	0.35
	4	0.20
2	1	0.81
	2	0.42
	3	0.27
	4	0.18

Table 24. Effect of soil moisture and distance from granule on control of millet with alachlor for greenhouse test ROI 3.

Soil moisture %	Distance from granule cm	Control
8	1	0.96
	2	0.70
	3	0.51
	4	0.36
	5	0.19
15	1	1.00
	2	0.97
	3	0.90
	4	0.73
	5	0.43

Table 25. Effect of granule depth and distance from granule on control of millet with alachlor for greenhouse test ROI 3.

Granule depth cm	Distance from granule cm	Control
0	1	0.98
	2	0.91
	3	0.80
	4	0.66
	5	0.39
1	1	0.98
	2	0.76
	3	0.60
	4	0.43
	5	0.24

Table 26. Effect of soil moisture and distance from granule on control of velvetleaf with atrazine for greenhouse test ROI 3.

Soil moisture %	Distance from granule cm	Control
8	1	0.68
	2	0.35
	3	0.26
	4	0.14
	5	0.09
15	1	0.80
	2	0.32
	3	0.10
	4	0.04
	5	0.05

Table 27. Effect of method of moisture addition and distance from granule on control of velvetleaf with atrazine for greenhouse test ROI 3.

Method of moisture addition	Distance from granule cm	Control
Subirrigation	1	0.70
	2	0.35
	3	0.22
	4	0.12
	5	0.06
Simulated rain	1	0.78
	2	0.32
	3	0.14
	4	0.06
	5	0.07

moisture with method of moisture addition, method of moisture addition with granule depth, and soil moisture with granule depth with method of moisture addition also affected control with distance from granule (Tables 28-30).

Table 28. Effect of soil moisture, method of moisture addition and distance from granule on control of velvetleaf with atrazine for greenhouse test ROI 3.

Soil moisture %	Method of moisture addition	Distance from granule cm	Control
8	subirrigation	1	0.66
		2	0.45
		3	0.32
		4	0.20
		5	0.09
	simulated rain	1	0.71
		2	0.26
		3	0.20
		4	0.07
		5	0.08
15	subirrigation	1	0.74
		2	0.25
		3	0.11
		4	0.03
		5	0.04
	simulated rain	1	0.86
		2	0.39
		3	0.09
		4	0.06
		5	0.06

Table 29. Effect of granule depth, method of moisture addition and distance from granule on control of velvetleaf with atrazine for greenhouse test ROI 3.

Granule depth cm	Method of moisture addition	Distance from granule cm	Control
0	subirrigation	1	0.54
		2	0.30
		3	0.16
		4	0.10
		5	0.06
	simulated rain	1	0.88
		2	0.36
		3	0.23
		4	0.09
		5	0.06
1	subirrigation	1	0.86
		2	0.41
		3	0.28
		4	0.13
		5	0.07
	simulated rain	1	0.69
		2	0.28
		3	0.06
		4	0.03
		5	0.08

Table 30. Effect of soil moisture, granule depth, method of moisture addition, and distance from granule on control of velvetleaf with atrazine for greenhouse test ROI 3.

Soil moisture %	Granule depth cm	Method of moisture addition	Distance from granule cm	Control
8	0	subirrigation	1	0.42
			2	0.34
			3	0.20
			4	0.17
		simulated rain	1	0.84
			2	0.32
			3	0.32
			4	0.11
	1	subirrigation	1	0.91
			2	0.56
			3	0.45
			4	0.24
		simulated rain	1	0.57
			2	0.19
			3	0.07
			4	0.02
15	0	subirrigation	1	0.66
			2	0.25
			3	0.11
			4	0.04
		simulated rain	1	0.91
			2	0.41
			3	0.14
			4	0.07
	1	subirrigation	1	0.82
			2	0.25
			3	0.10
			4	0.02
		simulated rain	1	0.81
			2	0.38
			3	0.04
			4	0.04

Radius-of-Influence

The radius-of-influence (ROI) of an individual herbicide granule, for a given set of conditions, was estimated by determining the relationship between control and the distance from the granule. The ROI was that distance at which the estimated average control was 0.75.

It was determined, after inspecting the data and fitting trial curves, that a relationship of the form

$$y = e^{-A(x-B)^2},$$

where y = control,

x = distance from granule, and

A and B = parameters dependent on conditions,

satisfactorily described control. Then, solving for x at y = 0.75,

$$\mathrm{ROI} = 0.536(A)^{-0.5}+B.$$

The estimates and standard deviations of A and B for the best fit of the relationship to the millet/alachlor data for each set of treatment conditions in greenhouse test ROI 3 are given in Table 31. Also included are the estimates of goodness of fit (R^2) and ROI.

The ROI's were larger for the 15% moisture content than for the 8% soil moisture. Simulated rain increased the ROI for the surface-applied granules on the low moisture soil but had little effect at the high moisture content or when the granules were placed 1 cm deep. The ROI was greater in all cases for the surface-applied granules than for the granules placed 1 cm deep. The data for each treatment, along with the fitted curve and confidence limits, are plotted in Figures 11 through 18. With the 8% soil moisture, control was most variable when the granule was

Table 31. Estimated means and standard deviations of the parameters for the fit of $y=e^{-A(x-B)^2}$ to the millet/alachlor data from greenhouse test ROI 3. Also included are the R^2 of the fit and the estimated ROI.

Treatment			A		B		R^2	ROI
Soil moisture	Granule depth	Method of moisture addition	Mean	σ	Mean	σ		
%	cm				cm	cm		cm
8	0	subirrigation	0.060	0.010	0.12	0.27	0.89	2.3
		simulated rain	0.042	0.013	0.40	0.53	0.70	3.0
	1	subirrigation	0.098	0.014	-0.04	0.19	0.93	1.7
		simulated rain	0.150	0.025	0.11	0.18	0.92	1.5
15	0	subirrigation	0.063	0.015	1.74	0.29	0.73	3.9
		simulated rain	0.062	0.011	1.82	0.22	0.81	4.0
	1	subirrigation	0.052	0.014	1.17	0.39	0.78	3.5
		simulated rain	0.091	0.012	1.74	0.15	0.90	3.5

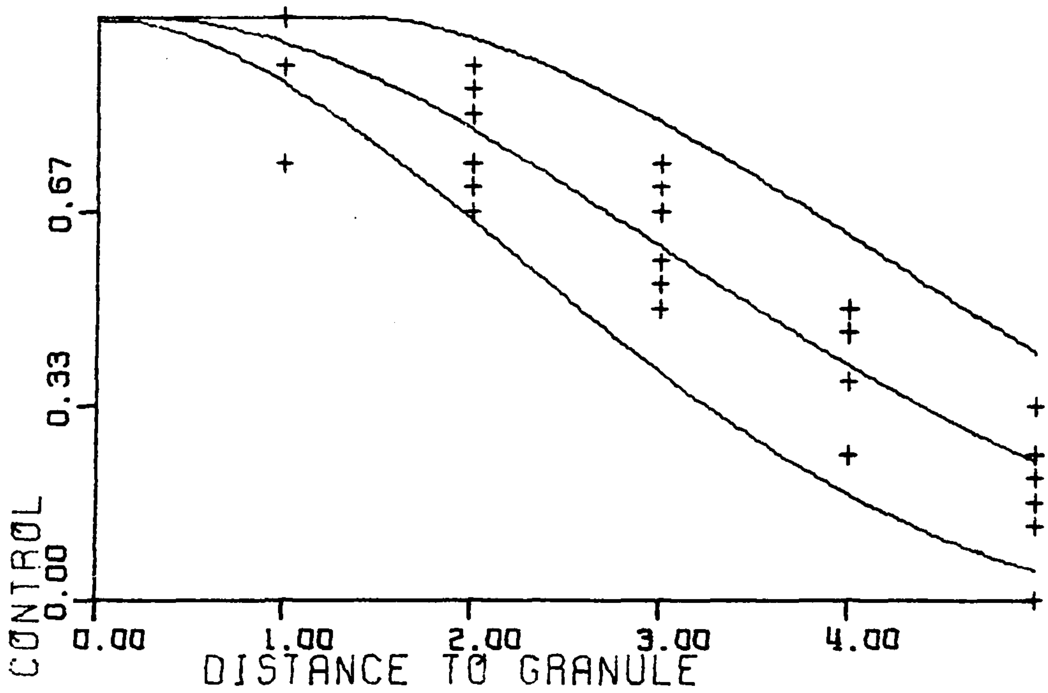

Figure 11. Control of millet with alachlor for 8% soil moisture, granule on surface, and subirrigation.

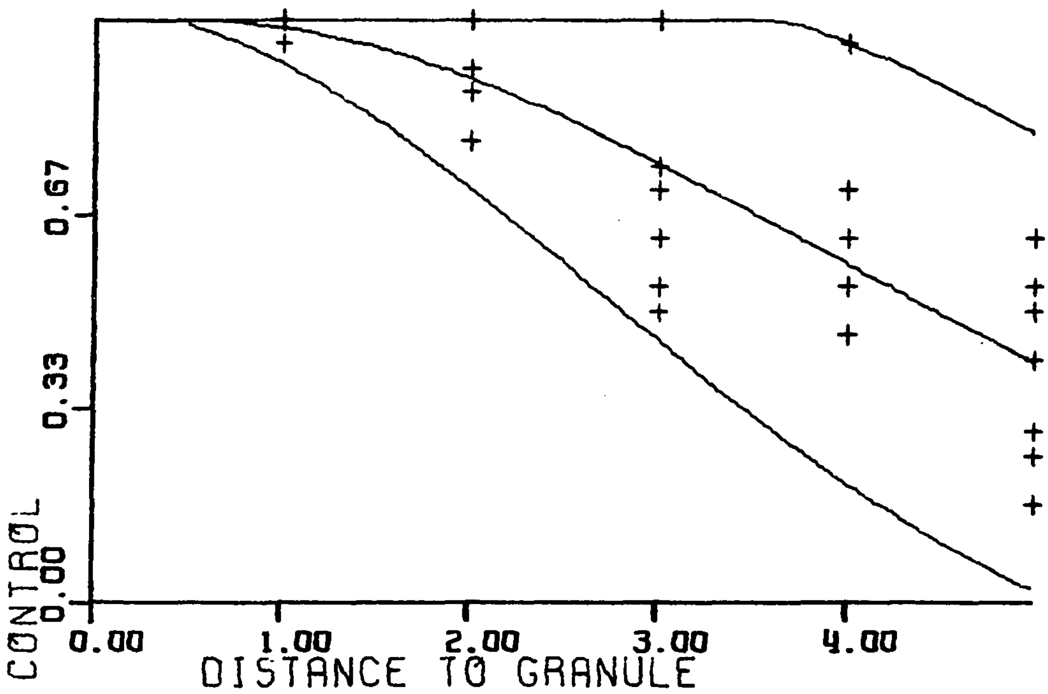

Figure 12. Control of millet with alachlor for 8% soil moisture, granule on surface, and simulated rain.

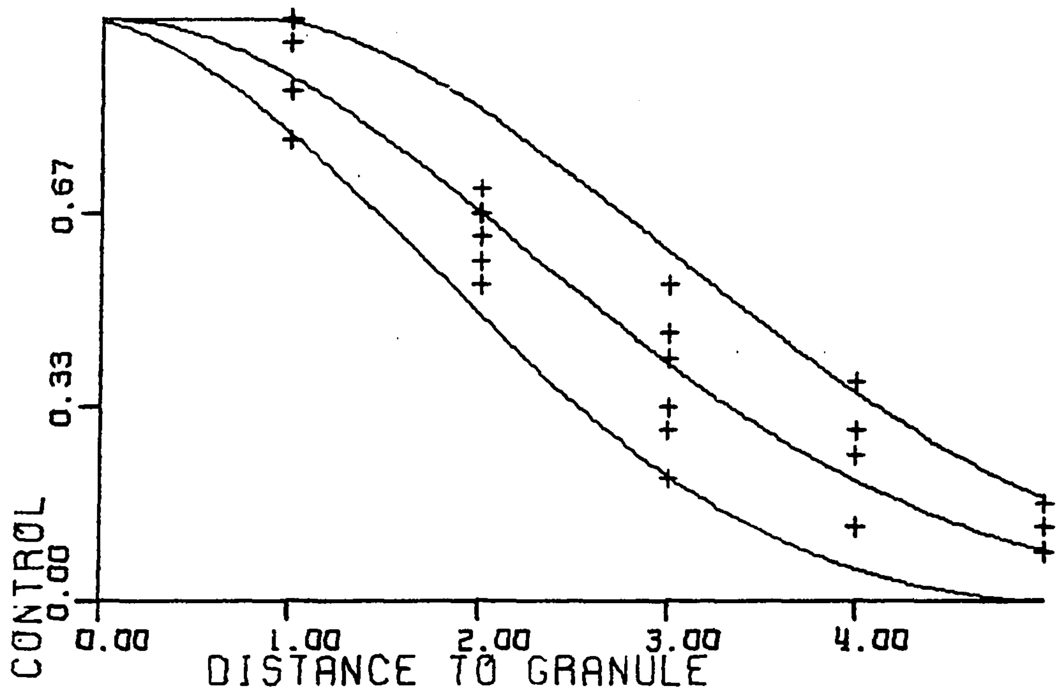

Figure 13. Control of millet with alachlor for 8% soil moisture, granule 1 cm deep, and subirrigation.

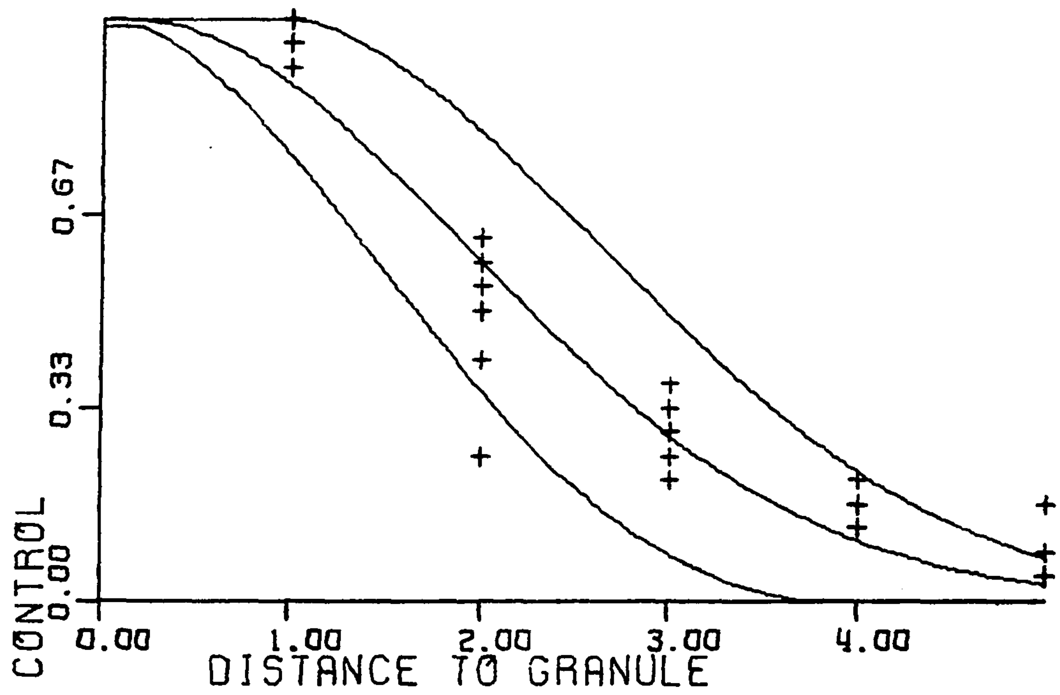

Figure 14. Control of millet with alachlor for 8% soil moisture, granule 1 cm deep, and simulated rain.

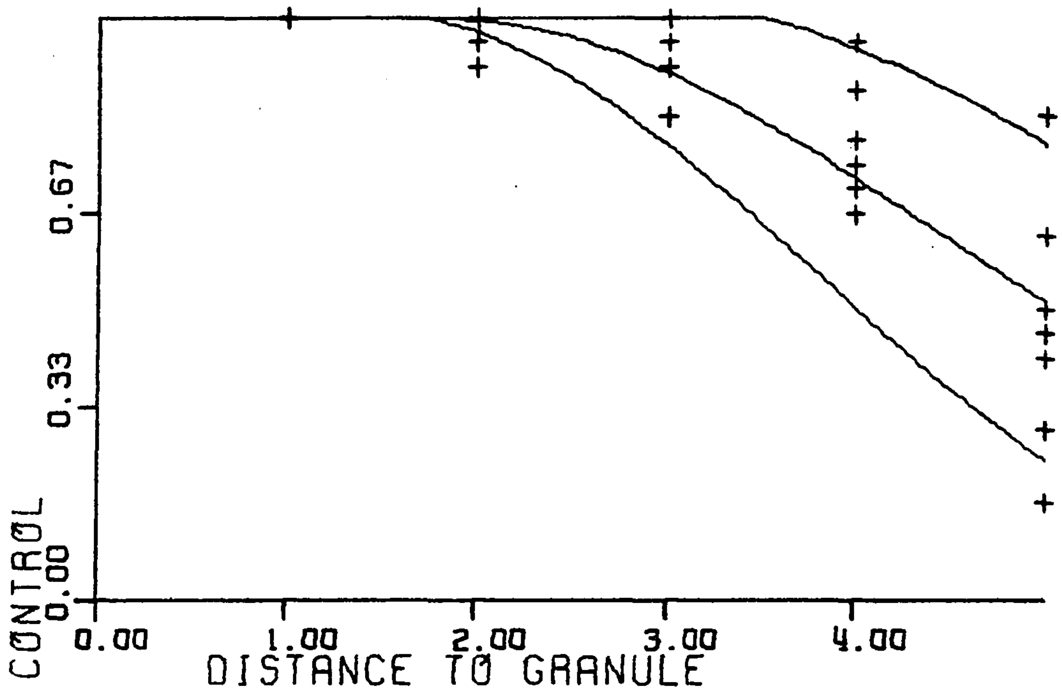

Figure 15. Control of millet with alachlor for 15% soil moisture, granule on surface, and subirrigation.

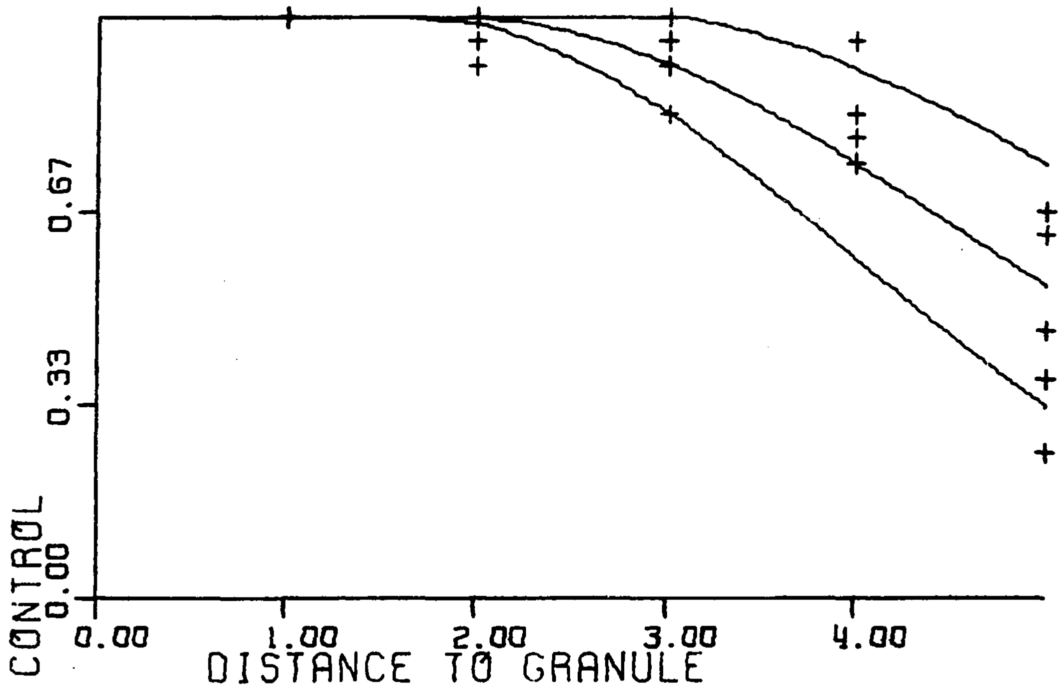

Figure 16. Control of millet with alachlor for 15% soil moisture, granule on surface, and simulated rain.

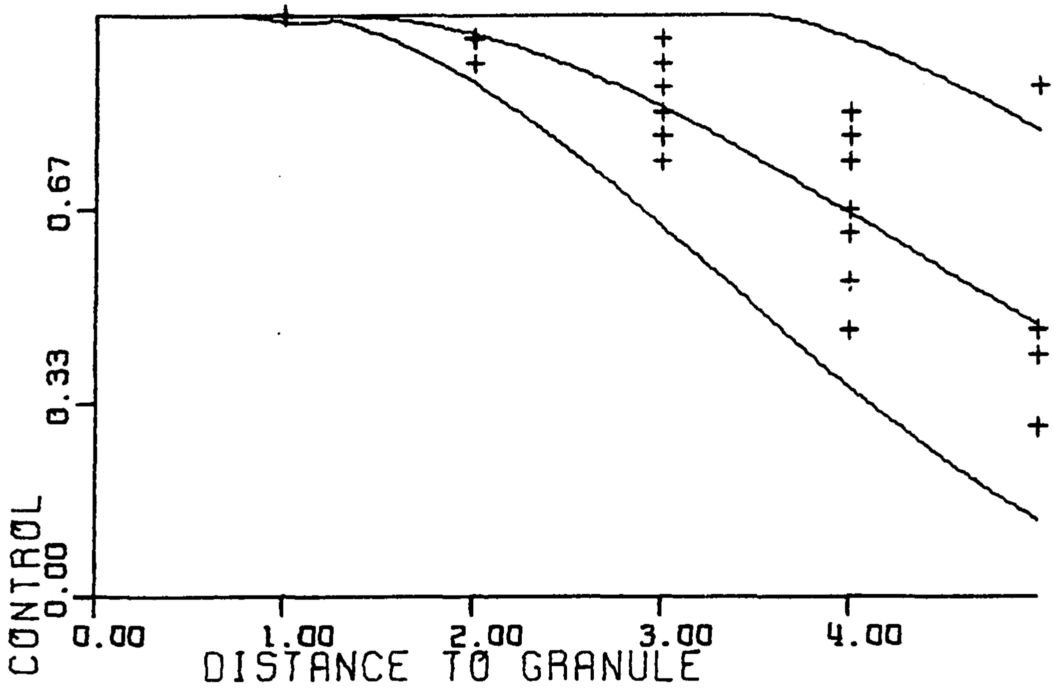

Figure 17. Control of millet with alachlor for 15% soil moisture, granule 1 cm deep, and subirrigation.

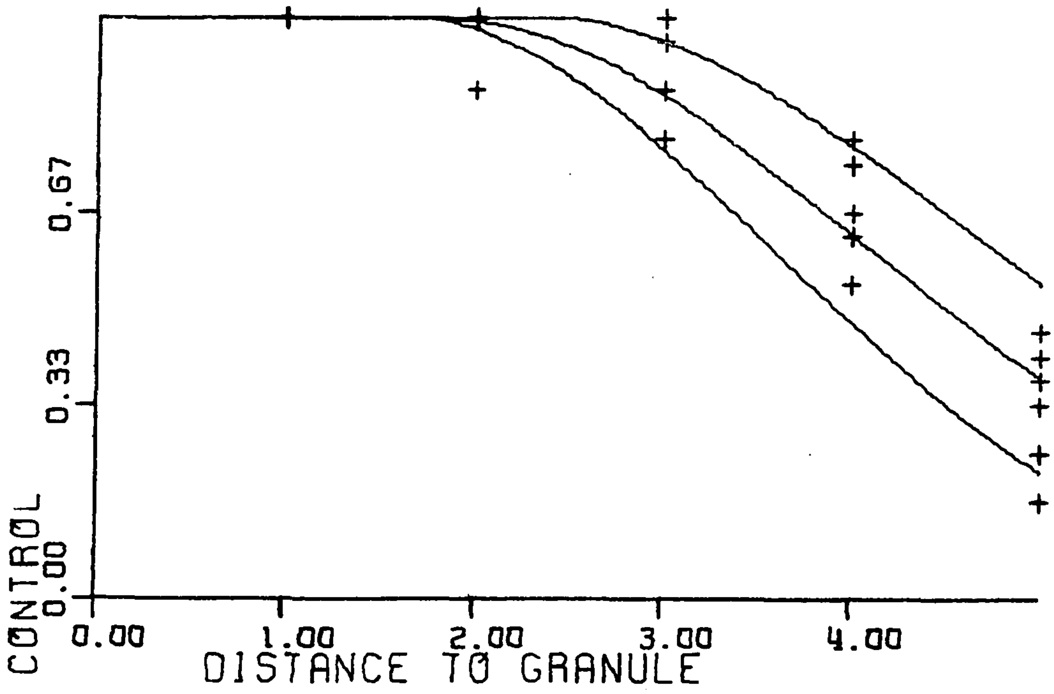

Figure 18. Control of millet with alachlor for 15% soil moisture, granule 1 cm deep, and simulated rain.

on the surface and moisture was applied as simulated rain. At 15% soil moisture, control was more variable when moisture was applied by subirrigation than as simulated rain.

The estimates and standard deviations of the parameters A and B for the fit of $y = e^{-A(x-B)^2}$ to the velvetleaf/atrazine data of greenhouse test ROI 3 are given in Table 32. Also included are the estimates of goodness of fit and ROI. The ROI for atrazine granules with velvetleaf was smaller and more variable than the ROI of alachlor granules with millet. The data for each treatment are plotted, with the fitted curve and confidence limits in Figures 19 through 26. Control was more variable when moisture was applied by subirrigation except at 15% soil moisture with moisture added as simulated rain. Variability was also greater at 8% soil moisture than at 15%.

The estimates and standard deviations of the parameters A and B for the fit of $y = e^{-A(x-B)^2}$ to the millet/alachlor data from the field ROI test are given in Table 33. When the granules were on the soil surface, control was variable. Variability decreased when the granules were placed beneath the soil. Control was most consistent when the granules and seeds were placed near the same depth.

The estimates and standard deviations of A and B for the fit of $y = e^{-A(x-B)^2}$ to the data for the control of millet with 24/48 mesh alachlor granules are given in Table 34. The parameter estimates indicate the curves have different shapes, but the ROI's and goodness of fit are nearly equal.

Table 32. Estimated means and standard deviations of the parameters for the fit of $y=e^{-A(x-B)^2}$ to the velvetleaf/atrazine data from greenhouse test ROI 3. Also included are the R^2 of the fit and the estimated ROI.

Treatment			A		B		R^2	ROI
Soil moisture	Granule depth	Method of moisture addition	Mean	σ	Mean	σ		
%	cm				cm	cm		cm
8	0	subirrigation	0.022	0.013	-5.18	2.17	0.28	0
		simulated rain	0.116	0.047	-0.54	0.54	0.58	1.0
	1	subirrigation	0.076	0.026	-0.42	0.54	0.62	1.5
		simulated rain	0.246	0.095	-0.52	0.37	0.63	0.6
15	0	subirrigation	0.206	0.092	-0.47	0.46	0.59	0.7
		simulated rain	0.306	0.081	0.36	0.20	0.84	1.3
	1	subirrigation	0.447	0.126	0.31	0.18	0.82	1.1
		simulated rain	0.330	0.104	0.23	0.23	0.78	1.2

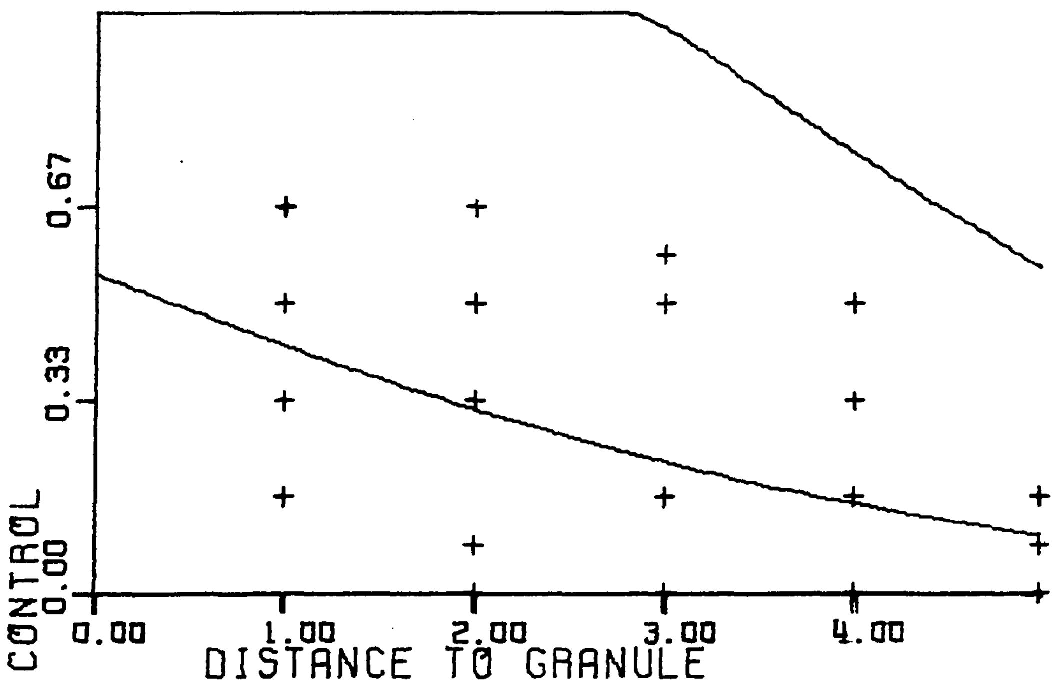

Figure 19. Control of velvetleaf with atrazine for 8% soil moisture, granule on surface, and subirrigation.

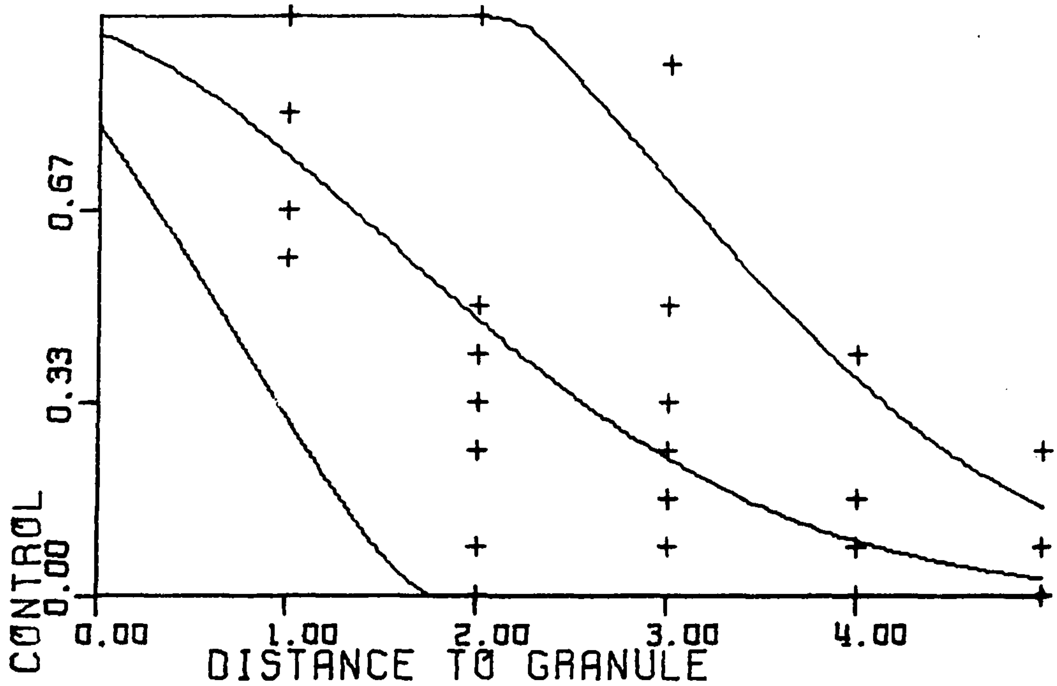

Figure 20. Control of velvetleaf with atrazine for 8% soil moisture, granule on surface, and simulated rain.

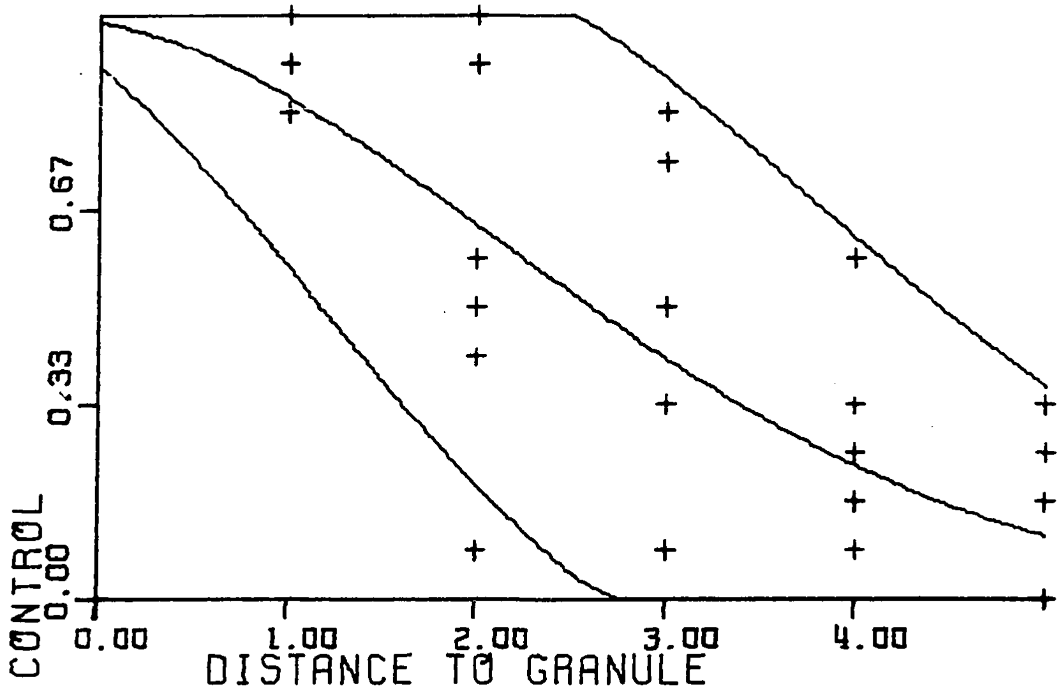

Figure 21. Control of velvetleaf with atrazine for 8% soil moisture, granule 1 cm deep, and subirrigation.

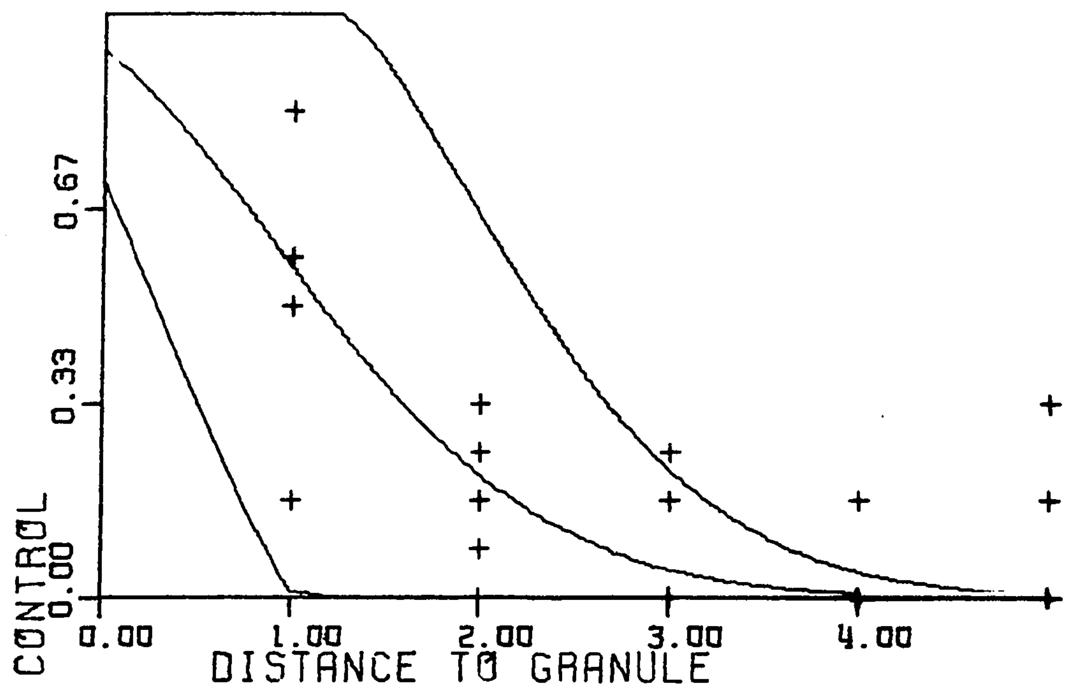

Figure 22. Control of velvetleaf with atrazine for 8% soil moisture, granule 1 cm deep, and simulated rain.

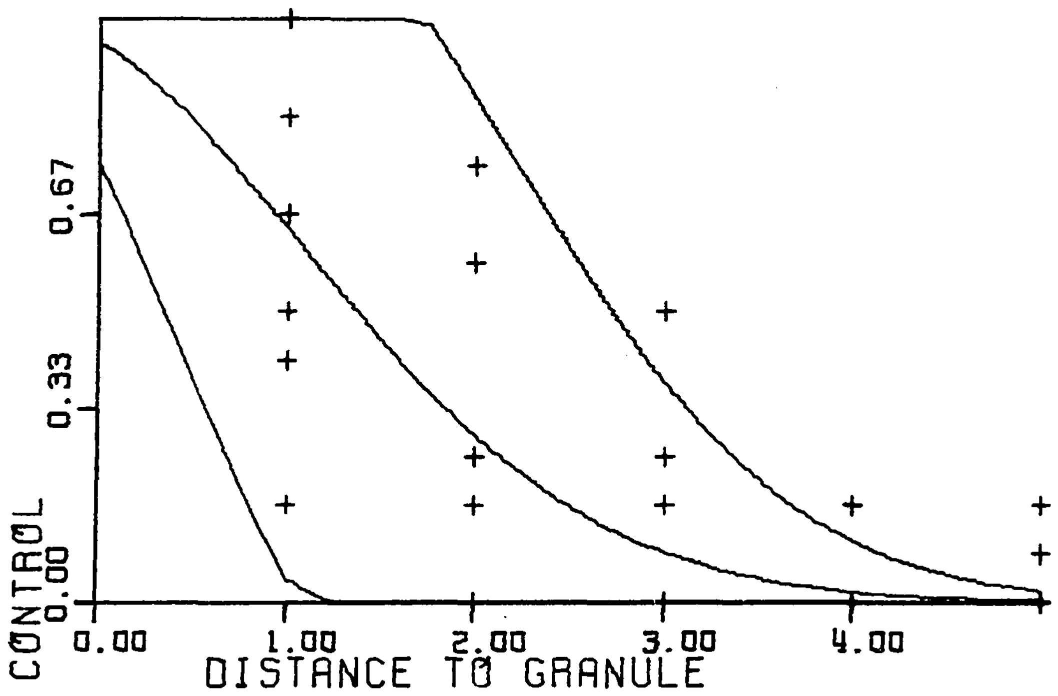

Figure 23. Control of velvetleaf with atrazine for 15% soil moisture, granule on surface and subirrigation.

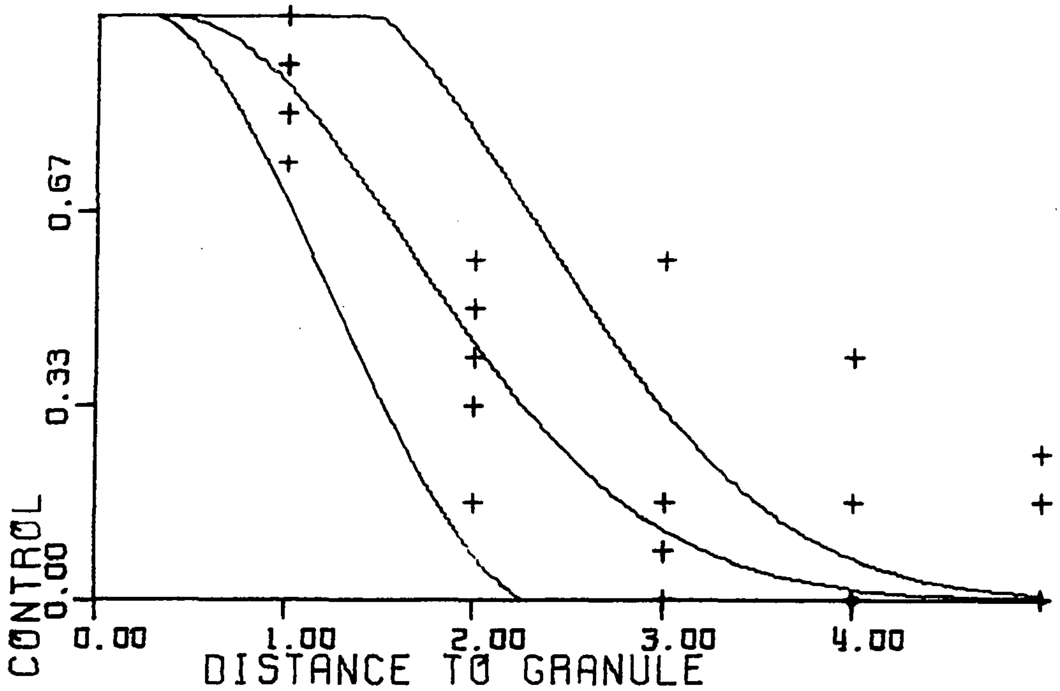

Figure 24. Control of velvetleaf with atrazine for 15% soil moisture, granule on surface and simulated rain.

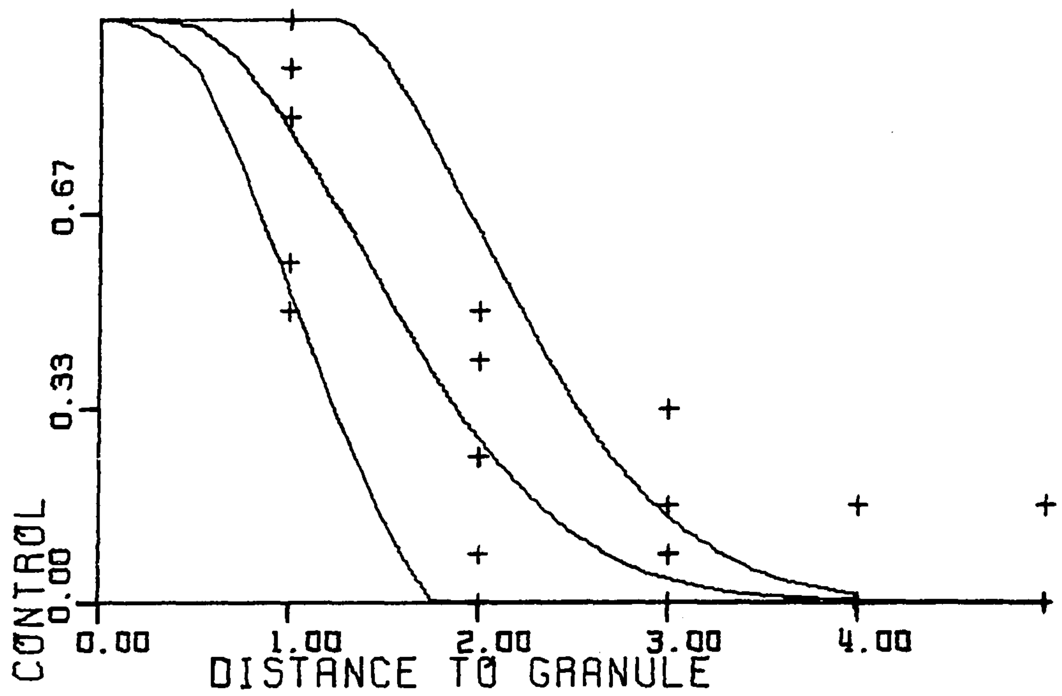

Figure 25. Control of velvetleaf with atrazine for 15% soil moisture, granule 1 cm deep, and subirrigation.

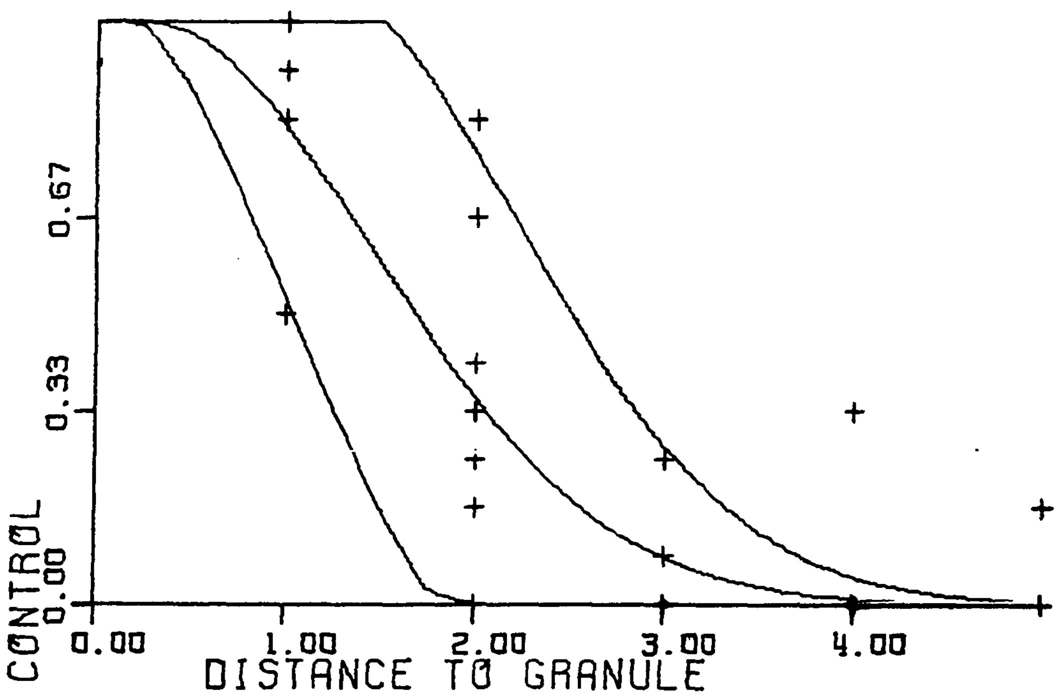

Figure 26. Control of velvetleaf with atrazine for 15% soil moisture, granule 1 cm deep, and simulated rain.

Table 33. Estimated means and standard deviations of the parameters for the fit of $y=e^{-A(x-B)^2}$ to the millet/alachlor data from field ROI test. Also included are the R^2 of the fit and the estimated ROI.

Treatment		A		B		R^2	ROI
Seed depth	Granule depth	Mean	σ	Mean	σ		
cm	cm			cm	cm		cm
1	0	0.37	0.17	0.06	0.33	0.75	0.95
	1	0.23	0.05	0.00	0.19	0.94	1.12
	2	0.44	0.10	0.20	0.14	0.94	1.02
	3	0.18	0.06	-0.58	0.35	0.85	0.67
	Check	0.01	0.04	-2.04	6.92		
2	0	-0.23	0.16	-0.33	0.65	0.60	0.79
	1	0.01	0.05	-1.26	0.66	0.72	0.34
	2	0.20	0.08	-0.59	0.46	0.75	0.62
	3	0.33	0.12	-0.08	0.27	0.84	0.85
	Check	0.01	0.04	-2.03	6.89		
3	0	0.07	0.05	-2.08	1.50	0.43	0.00
	1	0.12	0.04	-0.49	0.39	0.84	1.03
	2	0.23	0.08	-0.66	0.34	0.84	0.45
	3	0.14	0.03	-0.86	0.26	0.93	0.60
	Check	0.01	0.04	-2.03	6.89		

Table 34. Estimates of parameters of equation $y=e^{-A(x-B)^2}$, of R^2 and of ROI for greenhouse ROI test 4.

Time of simulated rain	A		B		R^2	ROI
	Mean	σ	Mean cm	σ cm		cm
Day after planting	0.21	0.06	0.30	0.27	0.78	1.20
Day plants emerged	-0.16	0.05	-0.03	0.34	0.70	1.14

Interaction of Areas-of-Influence

Regression of the area controlled by two granules (y_i) on distance between the granules (x_i) using the model

$$y_i = \beta_o + \beta_1 x_i + \beta_2 x_i^2$$

failed to indicate that the coefficients β_1 and β_2 were significantly different from zero. The estimates of the coefficients indicated an increase in area of control as granules were separated, followed by a decrease when the granules were separated still farther. However, the variability of the greenhouse test data made it necessary to conclude there was no interaction between areas-of-influence.

The results of the field test showed no significant effect of granule spacing on area-of-influence.

Granule Distribution

Control of millet with alachlor for greenhouse granule distribution test 1 is given in Table 35. Included are the average plant rating and the percent of plants rated 0.75 or higher. The values have been adjusted for the number of plants which failed to emerge in the check plots. The adjustment for the check treatments was made by solving for x in the following equation:

$$y = x + (1-x)\ (1-z)$$

where x = adjusted control; y = unadjusted control; and z = plant survival in check plot.

Table 35. Effect of soil moisture content, method of moisture addition, granule depth, granule distribution and granule density on control of millet with alachlor for greenhouse granule distribution test 1.

Treatment					Control	
Soil moisture	Moisture addition	Granule depth	Granule distribution	Granule density	0.75	Average
%		cm		granules/cm^2	%	
8	sub-irrigation	0	hexagonal	0.12	63	0.61
				0.24	80	0.78
			random	0.12	72	0.63
				0.24	85	0.76
		1	hexagonal	0.12	52	0.59
				0.24	63	0.76
			random	0.12	46	0.47
				0.24	65	0.68
	simulated rain	0	hexagonal	0.12	33	0.50
				0.24	65	0.52
			random	0.12	57	0.69
				0.24	45	0.62
		1	hexagonal	0.12	0	0.00
				0.24	35	0.74
			random	0.12	0	0.01
				0.24	0	0.00
15	sub-irrigation	0	hexagonal	0.12	66	0.70
				0.24	100	0.93
			random	0.12	52	0.53
				0.24	75	0.73
		1	hexagonal	0.12	23	0.26
				0.24	88	0.84
			random	0.12	46	0.50
				0.24	42	0.52
	simulated rain	0	hexagonal	0.12	96	0.84
				0.24	100	0.93
			random	0.12	80	0.80
				0.24	94	0.86
		1	hexagonal	0.12	44	0.47
				0.24	87	0.80
			random	0.12	35	0.41
				0.24	67	0.68

Control was better when soil was at 15% moisture than when at 8%. At the 15% soil moisture, better control was obtained with simulated rain than with subirrigation. At the 8% soil moisture, the best control was obtained when water was added by subirrigation. Surface-applied granules gave better control than granules placed 1 cm deep. Control was best with the combination of surface placement, 15% soil moisture, and simulated rain. Poorest control was with granules placed 1 cm deep in soil with 8% moisture when water was added as simulated rain.

Distribution indices for the granule distributions evaluated in this test were 0.48 and 0.49 respectively for the low and high density hexagonal lattice distributions. For the random distributions, α equalled 0.75 for the low density and 0.86 for the high.

Control with the hexagonal lattice granule distribution was better than with the random distribution. The importance of granule distribution depended upon herbicide granule density. The hexagonal lattice distribution gave the best control at the high density. Control at the low density was nearly equal for both distributions. For those treatments with granule ROI's near that which would give complete control with the hexagonal distribution, the control was directly related to uniformity of distribution. For those treatments with small ROI's, the control was mainly dependent on the number of herbicide granules present in the test area.

The average control adjusted for check treatments is plotted versus predicted control in Figure 27. The predicted control for a set of treatment conditions was the estimated coverage. Coverage for each

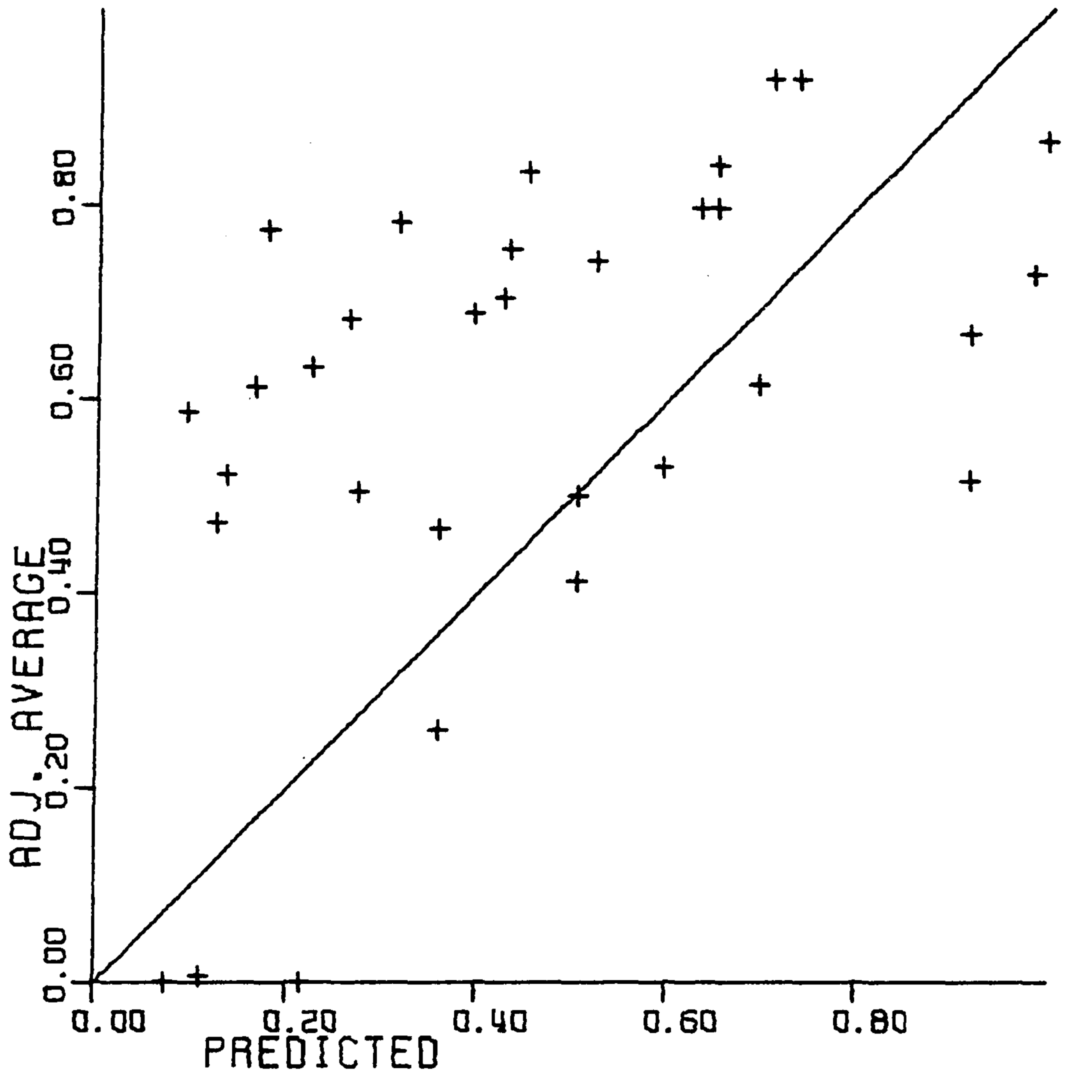

Figure 27. Average control of millet with alachlor adjusted for check treatments versus predicted control for greenhouse granule distribution test 1.

distribution treatment was calculated using the granule distribution for that treatment and the estimated ROI from greenhouse test ROI 3 for the same treatment conditions. The estimated coefficients for the fit of $y = \beta_o + \beta_1 x + \beta_2 x^2$ to the data are $\beta_o = 0.28$, $\beta_1 = 1.02$, and $\beta_2 = 0.42$. The values for β_o and β_1 were significantly different from zero.

The proportion of plants rated 0.75 or higher adjusted for the check treatments is plotted versus predicted control in Figure 28. The estimated coefficients for the fit of $y = \beta_o + \beta_1 x + \beta_2 x^2$ to these data are $\beta_o = 0.26$, $\beta_1 = 0.88$, and $\beta_2 = -0.19$. The values for β_o and β_1 were again significantly different from zero.

The experimental control tends to be greater than the predicted, especially for the midrange. This may be due to interaction of AOI's which in effect improves coverage.

Percent of plants rated 0.75 or higher, average control, and predicted control for the field granule distribution test are given in Table 36. These values are averages for 4 granule densities. The predicted control was based on estimated ROI's for corresponding seed and granule depth conditions from the field ROI test.

The predicted control was considerably lower than the experimental control. This was due in part to nonuniform soil moisture conditions in the test plot. Samples taken when the tests were planted indicated that the average soil moisture content in the ROI test area was 15%, while the moisture content in the granule distribution test area, only a meter away, was 23%. This moisture variation was due to the method of soil preparation and to lack of rain between soil preparation and planting.

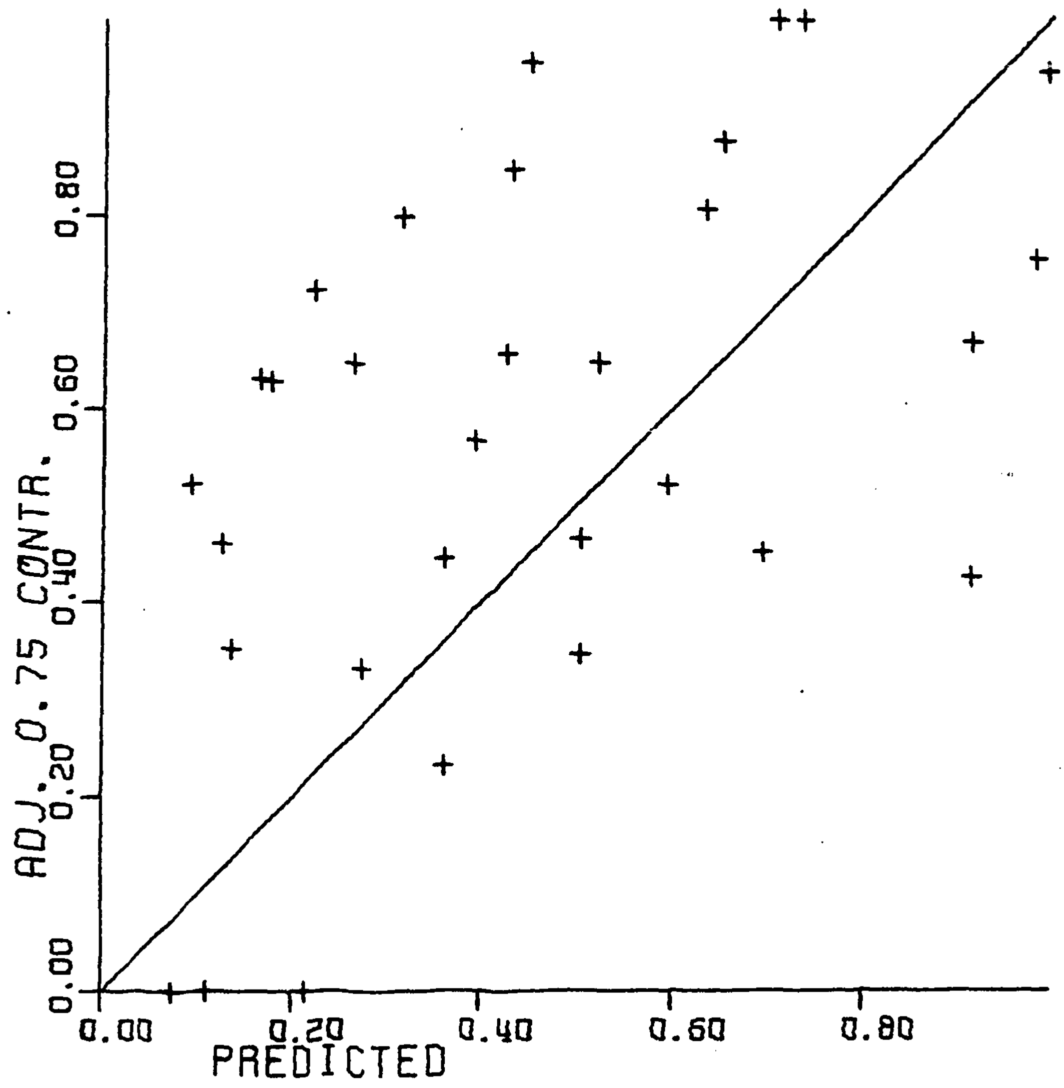

Figure 28. Proportion of plants rated 0.75 or better adjusted for check treatments versus predicted control for greenhouse granule distribution test 1.

Table 36. Effect of granule distribution and combination of seed and granule depth on control of millet with alachlor for field granule distribution test.

Treatment			Control		
Seed depth cm	Granule depth cm	Granule distribution	Experimental 0.75 %	Experimental average	Predicted
2	1	hexagonal	22	0.32	0.02
		square	38	0.41	0.01
		random	34	0.37	0.01
	check		5	0.05	0
1	0	hexagonal	46	0.49	0.08
		square	53	0.60	0.09
		random	50	0.54	0.08
	check		15	0.16	0
1	1	hexagonal	44	0.48	0.13
		square	44	0.50	0.15
		random	38	0.41	0.13
	check		9	0.09	0

The relationship of seed and granule depth affected control. The best control was with the granules on the surface and the seeds at 1 cm. Poorest control was with seeds planted 2 cm deep and granules placed at 1 cm.

Granule distribution had little effect on control.

The control of millet with 24/48 mesh alachlor granules for comparison of square lattice distribution with distribution from commercial applicator is given in Table 37. Included in the table for each distribution are distribution index, granule density, experimental control, predicted coverage, distribution efficiency, and distribution adequacy. Predicted coverage was computed using the estimated ROI from

Table 37. Square lattice distribution compared with distribution from commercial applicator for greenhouse granule test 2.

Distribution	α	ρ granules/cm^2	Experimental control	Predicted coverage	Distribution Efficiency	Distribution Adequacy
Square lattice	0.57	0.25	0.96	0.90	0.90	0.80
Commercial applicator	1.23	0.45	0.98	0.82	0.40	0.34

greenhouse ROI test 4.

The control with the commercial applicator distribution was higher than the predicted coverage partly because the granule fines were not included when computing the coverage. The distribution index of 1.23 indicates the applicator distribution was slightly aggregated. The distribution efficiency and distribution adequacy were much lower for the applicator distribution than for the square lattice distribution. These results indicate that equivalent control may be obtained with greater efficiency when herbicide granules are applied in a regular distribution.

SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate the area influenced by individual herbicide granules, to describe uniformity of granule herbicide distribution, and to relate control to distribution uniformity.

To attain these objectives, a series of greenhouse and field tests were conducted. The control of millet and velvetleaf was used to evaluate the performance of individual granules and of distributions of granules. The herbicides used in these tests were alachlor and atrazine. Several granule distributions were also evaluated theoretically.

The area influenced by individual granules was determined by evaluating average control, radius-of-influence (ROI), and decrease in control with distance from a granule.

Average control was the average rating of herbicidal effect on the plants in a fixed pattern about the granule. A rating scale of 0 to 1 (1 being complete control) was used for each plant. Acceptable control was arbitrarily chosen to be 0.75. Plants rated 0.75 were effectively controlled and would provide little competition for crop plants.

The ROI was defined as the radius of a circular area, centered at the granule, within which control was greater than or equal to 0.75. The circular area was called the area-of-influence (AOI). Analysis of the experimental data showed that the control (y) in terms of distance (x) from a granule could be described by

$$y = e^{-A(x-B)^2}.$$

The ROI for a set of conditions was found by fitting this equation to the control versus distance data for those conditions and solving for x with y = 0.75.

Effects of soil moisture, method of moisture addition (simulated rain or subirrigation), time between planting and rain, granule depth, and seed depth were measured. Each of these variables was found to affect the size of the area influenced by individual herbicide granules.

Alachlor granules influenced a larger area than atrazine granules.

Control of millet with alachlor increased with increases in soil moisture content, with decreases in granule depth, and with increases in seed depth. The effect of granule depth increased with time between planting and rain and decreased with soil moisture content. When the granule was at or above the seed depth, control was better than when the granule was placed below the seeds.

Control of velvetleaf with atrazine was higher with simulated rain at the low soil moisture, but at the high soil moisture subirrigation improved control. Control was better with simulated rain than with subirrigation when the granules were placed on the surface. However, when granules were placed 1 cm deep, control was better with subirrigation.

Control tended to be most consistent when granules and seeds were placed near the same depth. Control was most variable when granules were placed on the surface.

A method (described by Pielou, 1959) based on the shortest distance between herbicide granules and randomly selected points was used to describe granule distribution uniformity. Distribution index was the statistic used to measure and compare uniformity of granule distributions. The distribution index was defined as the product of π, the granule density (in granules per unit area), and the average squared shortest distance between random points and individual granules. The distribution index has a value of 1 for a random distribution. The index decreases as the distribution becomes more regular (equals approximately 0.5 for a hexagonal lattice) and increases as the distribution becomes more aggregated.

The importance of uniform granule distribution was evaluated by determining the responses of granule density needed for adequate control, coverage, distribution efficiency, and distribution adequacy to changes in distribution index.

For a given set of conditions, the granule density needed for acceptable control was found to increase linearly with distribution index. The slope of the relationship increased as the area controlled by a granule decreased.

Coverage was defined as that proportion of the surface area within the AOI of one or more granules. Coverage decreased as the distribution index increased. Distribution efficiency was calculated by dividing coverage by coverage plus overlap. Distribution efficiency also decreased as distribution index increased.

Distribution adequacy, the product of coverage and distribution efficiency, indicated how efficiently and completely the granule distribution covered the area. The distribution adequacy decreased as distribution index increased. The response was greatest for combinations of granule density and ROI for which coverage with a uniform distribution was high without excessive overlap. Under these conditions, the distribution adequacy decreased from 0.8 (the theoretical maximum for circular AOI's) when distribution index equaled 0.5 to 0.35 at a distribution index of 1.2. When granule density was excessive, distribution adequacy was low, because distribution efficiency was low, and was not responsive to changes in distribution index. When coverage was low, distribution adequacy was low and again was not responsive to changes in distribution uniformity.

Random and regular lattice granule distributions were compared in greenhouse and field tests. When coverage for regular lattice distributions was high, control decreased as distribution index increased. When coverage was low, control depended on granule density.

The following conclusions were drawn from this study:

1. The distribution index, based on the shortest distances between random points and herbicide granules, can be used to compare uniformity of herbicide granule distributions.

2. The herbicide rate needed to maintain acceptable control was linearly proportional to the distribution index. The slope of this relationship decreased as the area controlled by each granule increased. A random distribution of herbicide granules would require approximately twice as much herbicide for control as would a hexagonal lattice distribution.

3. The effect of uniformity of granule distribution on control was important only when herbicide rate was just adequate to give complete

coverage with a uniform distribution. When herbicide rates were either excessive or inadequate, control was not responsive to distribution index.

4. The equation

$$y = e^{-A(x-B)^2}$$

was found to describe control (y) as function of distance (x) from granule.

5. The area controlled by an individual granule was affected by soil moisture, time between granule application and rain, and method of moisture application (simulated rain or subirrigation). Simulated rain improved control when granules were placed on the surface. Control of millet with alachlor increased with increase in soil moisture.

6. Seed depth and granule depth affected the area controlled by an individual granule. The control of millet with alachlor increased with increase in seed depth and with decrease in granule depth. The control of millet with alachlor was best when granules were placed above the seeds.

7. The area controlled by an individual granule depended on the plant and herbicide combination. The area of millet influenced by an alachlor granule was larger than the area of velvetleaf influenced by an atrazine granule.

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APPENDIX 1

Experimental Soils

Three loam soils from the Clarion-Nicollet-Webster soil association were used in the greenhouse and the field tests. Table A1-1 gives the particle size distribution for each of the 3 soils.

Table A1-1. Mechanical composition of experimental soils.[a]

Soil	Separates			
	Sand %	Coarse silt %	Fine silt %	Clay %
Black loam (greenhouse)	43.0	20.1	13.6	23.3
Brown loam (greenhouse)	45.6	16.4	19.0	19.0
Black loam (field)	35.8	22.0	15.1	27.1

[a]Analyzed by Iowa State University Soil Survey Laboratory.

Figure A1-1 shows the soil moisture desorption curves for the 3 soils. The data were obtained following a procedure similar to that outlined in the Iowa State University Soil Physics Laboratory Manual. A Tempe cell with high flow rate ceramic plate was used for pressures up to 0.15 bar, a 3-bar ceramic plate for pressures to 1 bar, and a 15-bar ceramic plate for pressures to 14 bars.

The phosphorus, potassium and organic matter contents, buffer pH, and cation exchange capacity of each soil are given in Table A1-2.

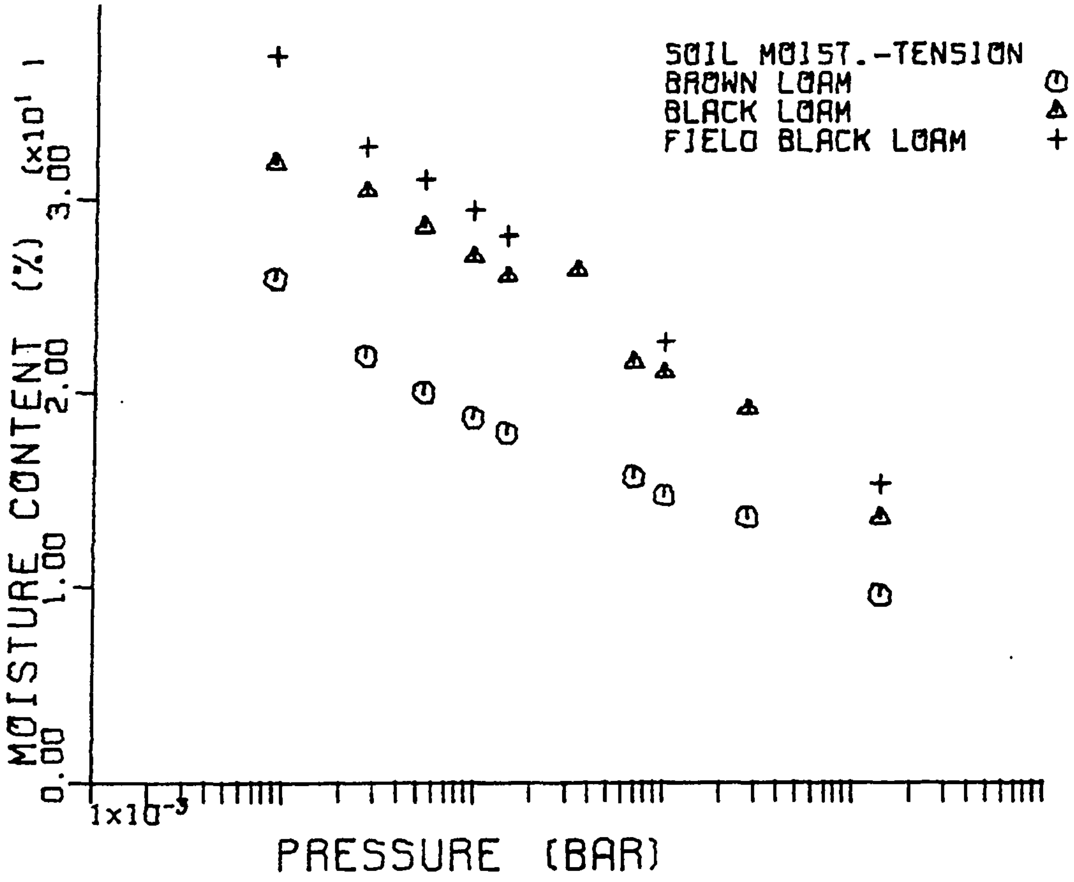


Figure A1-1. Soil moisture desorption curves.

Table A1-2. Nutrient content, organic matter content, pH and cation exchange capacity of experimental soils.[a]

Soil	P	K	Organic matter	pH	C.E.C.	Exchange- able Ca	Exchange- able Mg
	μg/g	μg/g	%		meq/100g	meq/100g	meq/100g
Black loam (greenhouse)	40	125	4.0	7.1	24.6	21.2	3.0
Brown loam (greenhouse)	44	105	1.9	6.8	13.7	8.7	2.7
Black loam (field)	42	140	3.3	6.5	18.2	11.2	2.7

[a]Analyzed by Minnesota Valley Testing Laboratories, Inc., Nevada, Iowa. Available phosphorus extracted with Bray's No. 1 solution and measured photometrically. Exchangeable potassium extracted with ammonium acetate and measured with atomic absorption spectrophotometer.

Plants

The plants selected for this study were foxtail millet (*Setaria italica* (L.) Beauv.) and velvetleaf (*Abutilon theophrasti* Medic). Foxtail millet is an annual grass related to green foxtail (*Setaria viridis* (L.) Beauv.), yellow foxtail (*Setaria glauca* (L.) Beauv.) and giant foxtail (*Setaria faberii* Herrm.) which are common weeds in corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.). It was used because of its high germination rate.

Velvetleaf was chosen because it is one of the major annual broadleaf weeds of corn and soybeans and because its seed dormancy was easily broken and a high germination rate obtained.

Boiling Time Needed to Break Velvetleaf Dormancy

Velvetleaf seeds which had been stored in a refrigerator were placed in boiling water to break their dormancy. A test was made to determine the boiling time for maximum germination. A strainer was placed in a 1000 ml beaker of water and the water was heated to boiling. Groups of 50 seeds were dumped into the water and left from 5 to 50 sec. The seeds were removed with the strainer and placed on a paper towel to cool and dry. The seeds were then placed in petri dishes on filter paper which had been moistened. The dishes were covered and placed in an incubator at 23°C. After 3 days the percent germination was determined (Table A1-3). Based on this test a 10-sec boiling treatment was selected for breaking velvetleaf dormancy.

Table A1-3. Time in boiling water versus germination percentage for velvetleaf seeds.

Time sec	Germination %
0	10
5	96
10	98
15	96
20	86
30	80
40	68
50	68
60	46

Plant Emergence

Analysis of the check stars in greenhouse test ROI 3 showed no significant effect of initial soil moisture or method of moisture addition on emergence of either millet or velvetleaf. Velvetleaf averaged 94% emergence and millet 80%. Since two millet seeds were planted per location, the probability of at least one plant surviving at each location was 96%. The plant emergence data for the check stars is given in Table A1-4.

For greenhouse granule distribution test 1, the emergence rate in the check plots was approximately 60% for the 8% soil moisture and 70% for the 15% soil moisture.

Table A1-4. Effect of plant, soil moisture, and method of moisture addition on plant emergence for greenhouse test ROI 3.

Plant	Soil moisture %	Method of moisture addition	Plant emergence %
Millet	8	subirrigation	80
		simulated rain	82
	15	subirrigation	77
		simulated rain	79
Velvetleaf	8	subirrigation	90
		simulated rain	94
	15	subirrigation	94
		simulated rain	96

Herbicides

Atrazine

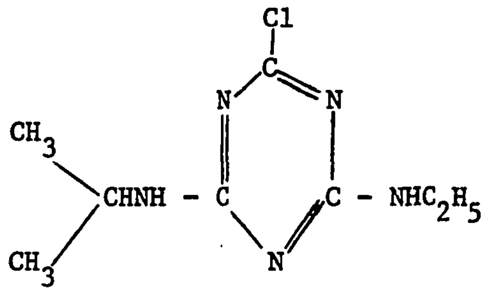
Atrazine is a widely used selective herbicide for control of broadleaf and grassy weeds in corn, sorghum, sugarcane, pineapple, and turfgrass sod. Granular formulations are not sold except for nonselective control of vegetation. Agricultural granules were withdrawn in 1963 because of nonperformance and soil residual problems. Many crops, including sugarbeets, tobacco, oats, and several vegetable crops are very sensitive to atrazine. Chemical and physical properties of atrazine are given in Table A1-5. Atrazine is absorbed through roots, shoots, and foliage. Following absorption, it is translocated acropetally in the xylem and accumulates in the apical meristems. Atrazine acts as a photosynthetic inhibitor and may have additional effects.

Atrazine adsorption on soils increases with increasing clay or organic matter content. Leaching is limited by this adsorption and atrazine is normally not found below the upper foot of soil in detectable quantities. The adsorption is not irreversible and desorption often occurs readily, depending on temperature, moisture, and pH.

Alachlor

Alachlor is used for control of most annual grasses and some broadleaf weeds. Absorption by plants is mainly through the germinating plant shoots with some absorption through the roots. Alachlor is

Table A1-5. Chemical and physical properties of atrazine.[a]

Chemical name:	2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine	
Trade name:	AAtrex	
Structural formula:		
Molecular weight:	215.7	
Molecular formula:	$C_8\ H_4Cl\ N_5$	
Vapor pressure:	Temperature °C	mm Hg
	10	5.7×10^{-8}
	20	3.0×10^{-7}
	30	1.4×10^{-6}
	50	2.3×10^{-5}
Solubility in water:	33 ppmw at 27C	
Acute oral toxicity:	LD_{50} - rats: 3080 mg/kg	
	LD_{50} - mice: 1750 mg/kg	

[a]Weed Science Society of America (1970).

translocated throughout the plant with highest concentrations in the vegetative parts. Information on mode of herbicidal action is not complete, but it is speculated that protein synthesis is inhibited.

Alachlor is adsorbed by colloidal particles in the soil. Persistance at recommended rates is only 6 to 10 weeks due to microbial and chemical breakdown.

Chemical and physical properties of alachlor are given in Table A1-6.

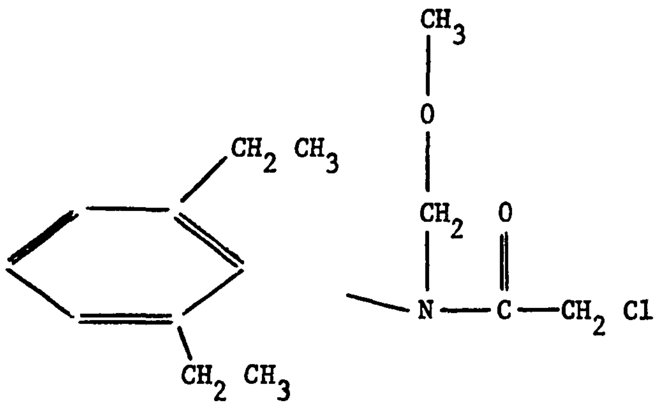
Preparation and Selection of Herbicide Granules

The 8/10 mesh attapulgus clay LVM 10% alachlor granules used were impregnated by Monsanto Company. The 24/48 mesh 10% alachlor granules used were a commercial formulation also prepared by Monsanto.

Atrazine granules were prepared in the laboratory using the following procedure. Twenty-five grams of atrazine 80W was placed in each of five 250-ml flasks to which had been added 100 ml of chloroform. The flasks were agitated for 1 hr on a shaker, allowed to stand for 16 hr, and agitated again for 1 hr after which the mixture was filtered. Four hundred grams of attapulgus LVM 8/15 mesh granules were wetted with the solution. The chloroform was evaporated, with aid of an air stream, while the granules were tumbled slowly. Wetting and evaporation were repeated until the solution was gone.

In evaluations with large (8/15 or 8/10 mesh) granules, only those granules which weighed between 8 and 10 mg as measured on a Cahn electrobalance were used. The small (24/48 mesh) granules were selected from a

Table A1-6. Chemical and physical properties of alachlor.[a]

Chemical name:	2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide
Trade name:	alachlor
Structural formula:	
Molecular weight:	269.8
Molecular formula:	$C_{14}H_{20}Cl\ NO_2$
Vapor pressure:	Approximately 0.02 mm Hg at 100C
Solubility in water:	148 ppmw at 25C
Acute oral toxicity:	LD_{50} - rats: Emulsifiable concentrate - 0.48 kg/l - 1800 mg/kg Granules - 10% - 9300 mg/kg

[a]Weed Science Society of America (1970).

container of granules but were not weighed. Table A1-7 gives a weight frequency distribution of 100 randomly selected 24/48 mesh granules.

Table A1-7. Weight frequency distribution of 24/48 mesh alachlor granules.

Granule weight mg	Frequency
<0.02	8
0.02-0.04	13
0.04-0.06	16
0.06-0.08	12
0.08-0.10	12
0.10-0.12	12
0.12-0.14	6
0.14-0.16	11
0.16-0.18	5
>0.18	5

Frequency distributions of granule weights for the 8/10 mesh alachlor granules and 8/15 mesh atrazine granules are given in Table A1-8.

Table A1-8. Granule weight frequency distributions for 8/10 mesh alachlor granules and 8/15 mesh atrazine granules.

Granule weight mg	Frequency	
	8/10 mesh alachlor granules	8/15 mesh atrazine granules
< 2	0	1
2- 4	3	44
4- 6	22	72
6- 8	80	48
8-10	62	28
10-12	23	6
12-14	6	1
14-16	2	0
16-18	0	0
>	2	0

Herbicide Content versus Granule Weight

Ten granules impregnated with alachlor and 10 impregnated with atrazine were analyzed with a gas chromatograph to test the hypothesis that the amount of herbicide adsorbed on a granule is proportional to the weight of the granule. The granules were weighed on the Cahn electrobalance. The granule weights, active ingredient, and weight of active ingredient are given in Table A1-9.

Table A1-9. Herbicide active ingredient versus granule weight.

Alachlor			Atrazine		
Granule weight mg	Active ingredient mg	Active ingredient %	Granule weight mg	Active ingredient mg	Active ingredient %
5.99	0.46	8	6.08	0.87	14
5.93	0.80	13	6.11	1.13	18
6.97	0.68	10	6.98	1.15	16
8.00	0.96	12	8.10	1.08	13
8.96	0.78	9	9.06	1.20	13
8.96	1.04	12	9.00	1.10	12
10.10	0.90	9	9.81	2.12	21
11.04	1.53	14	10.86	2.15	20
12.04	1.40	12	11.92	1.55	13
11.97	1.60	13	12.15	1.99	16

A regression analysis of percent active ingredient versus granule weight showed no significant effect. The mean percent alachlor for the granules analyzed was 11.1% or slightly higher than the nominal formulated value of 10%. The atrazine granules averaged 15.9%, which was lower than the 20% formulation goal.

A significant increase in amount of active ingredient with increase in granule weight was found for both types of compounds. The results indicate that the amount of active ingredient is proportional to the granule weight and that the percentage concentration is not dependent on granule weight.

Radius-of-Influence as Function of Granule Weight

An experiment was conducted to determine whether granule weight affected the area controlled by an individual herbicide granule. Granules were weighed on an electrobalance to within ± 0.05 mg of the nominal weight, and granules with weights from 4 to 13 mg were selected. The granules were placed 1 cm deep at the center of stars of seeds planted 1 cm deep. The seeds were planted in 8% moisture soil and received 2 cm of water by subirrigation the day after planting. A regression analysis failed to show a significant relationship between granule weight and average control of the plants in the star. The data are given in Table A1-10. It appears therefore that although the amount of active ingredient is related to granule weight, the effect of the difference in active ingredient, for the size granules tested, is not enough to affect the area controlled.

Table A1-10. Effect of granule weight on average control of plants in star.

Granule weight	Average control	
	Millet with	Velvetleaf
mg	alachlor	with atrazine
4	0.32	0.18
4	0.43	0.15
5	0.33	0.07
5	0.43	0.30
6	0.33	0.22
6	0.36	0.25
6	0.33	0.35
6	0.31	0.12
7	0.30	0.17
7	0.24	0.18
8	0.48	0.10
8	0.28	0.20
9	0.33	0.25
9	0.43	0.20
9	0.27	0.20
9	0.26	0.23
10	0.44	0.30
10	0.37	0.22
11	0.33	0.28
11	0.38	0.18
12	0.24	0.13
12	0.33	0.15
12	0.32	0.18
12	0.31	0.38
13	0.28	0.42
13	0.29	0.13

APPENDIX 2

Test Pan Preparation

In all greenhouse tests the plants were grown in plastic pans 26.5 cm long, 19 cm wide, and 9 cm deep. A rubber tube, used for subirrigation, was placed so it extended from the top of one corner down to the bottom of that corner, diagonally across the bottom to the opposite corner and up to the top. Holes were cut in the portion of the tube lying along the bottom. Sand was then added to cover the hose and to fill the pan to a depth of 2 cm. Soil of the desired moisture content was added and leveled to the depth of the deepest seed and/or granule placement. The seeds and/or granules were placed using a template. Additional soil was added and the procedure repeated for each additional seed and/or granule depth. Soil was then added and leveled at 1 cm below the top of the pan. The pan was placed in the greenhouse where rain treatments applied with the paint sprayer or subirrigation treatments, through the tube, were applied as specified.

The planting patterns and granule placement locations are shown in Figures A2-1 through A2-3. Figure A2-1 shows the granule and seed placement pattern used for greenhouse test ROI 1, ROI 2, and ROI 4. The pattern for greenhouse test ROI 3 is shown in Figure A2-2. For greenhouse granule distribution test 1, the millet and velvetleaf were planted in square lattice patterns with seeds spaced 1 and 2 cm respectively. The granule distributions for this test are shown in Figure A2-3.

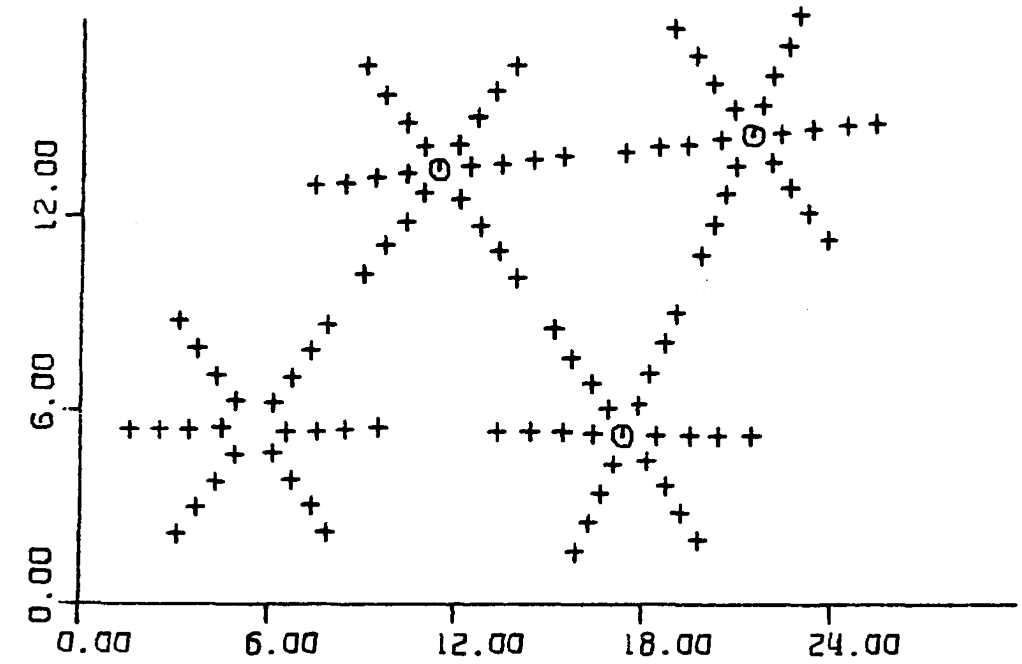


Figure A2-1. Star pattern used for seed placement in greenhouse tests ROI 1, ROI 2, and ROI 4. O's indicate granule locations.

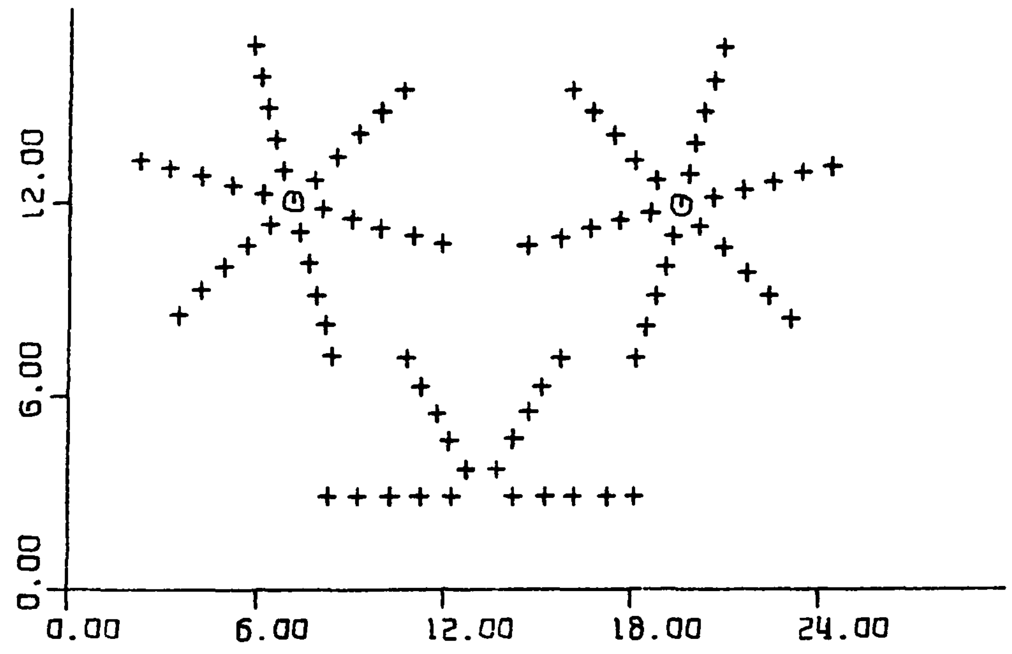


Figure A2-2. Star pattern used for seed placement in greenhouse test ROI 3. O's indicate granule locations.

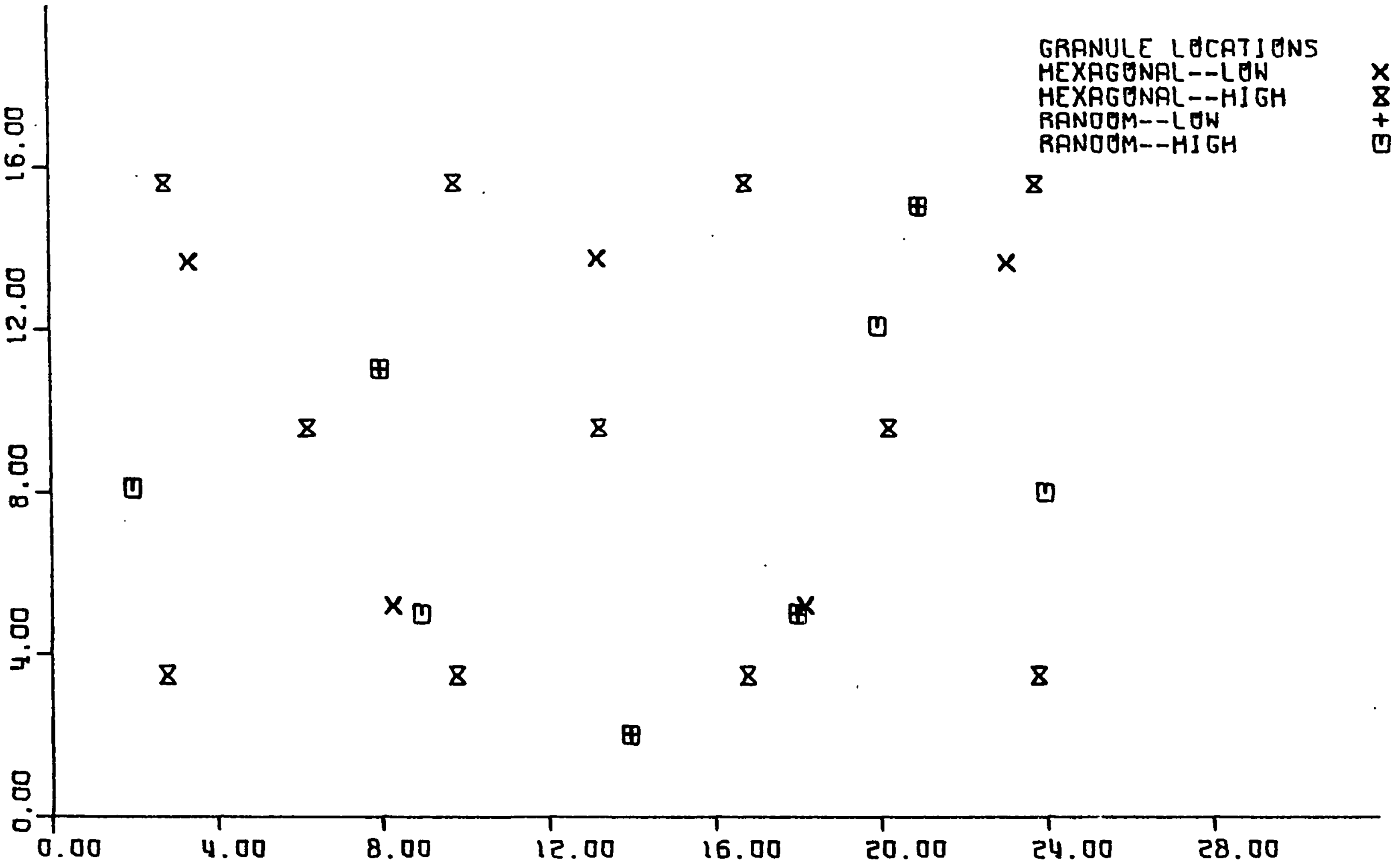


Figure A2-3. Location of granules for 4 distributions of greenhouse granule distribution test 1.

Soil Preparation

The soil was prepared by grinding in a hammermill and sieving through a 0.635 cm screen in a rotary sieve. The moisture content of the soil was determined, and the required amount of water added to bring the moisture to the desired level. The water was added with a paint sprayer while the soil was being stirred. The soil was then placed in plastic bags until used. All moisture samples were determined by the oven dry method with the soil placed in an air circulating oven at 100°C for 3 days.

Field Plot Preparation

The field plot was disked, plowed and disked twice, all in the spring. A square frame was pressed 5 cm into the soil, and the soil in the frame was removed. Soil was then sieved through a 0.635 cm screen and leveled at the depth of the deepest seed and/or granule placement. The seeds and/or granules were placed with a template. This procedure was repeated for each depth of seed or granule placement. The soil was then leveled to that of the surrounding soil. The templates were positioned with the aid of two wooden dowels pushed into the soil at opposite corners of the plot. These pegs were used for orientation when the plant growth condition was rated.

Temperature and Rainfall Conditions

The temperature and rainfall data for the months of May and June are given in Table A2-1. These data were from the Agronomy and

Table A2-1. May and June temperature-rainfall data.

May				June			
Day	Temperature Max. °C	Temperature Min °C	Rainfall cm	Day	Temperature Max °C	Temperature Min °C	Rainfall cm
1	17	11	1.1	1	27	12	
2	13	-1	1.4	2	27	17	0.4
3	16	1		3	27	17	0.9
4	19	2		4	27	14	1.2
5	19	10	0.4	5	24	14	0.2
6	20	12	0.5	6	26	12	
7	14	12	5.1	7	32	16	
8	24	9	0.2	8	33	19	
9	24	13	0.3	9	34	14	
10	23	8	0.4	10	33	19	
11	21	8	T	11	33	21	
12	19	4		12	32	18	1.0
13	18	3		13	28	14	
14	16	3	T	14	29	16	
15	21	2		15	29	19	0.7
16	21	8		16	32	22	0.2
17	21	3		17	32	15	
18	28	10		18	31	15	2.1
19	28	11		19	24	13	
20	26	9		20	23	12	
21	26	14	0.5	21	26	13	
22	26	16		22	28	12	
23	28	7		23	33	16	
24	28	12	0.2	24	31	16	
25	22	9		25	32	20	
26	20	9	0.9	26	31	18	
27	15	12	4.8	27	29	16	
28	18	11	0.9	28	26	12	
29	19	11	0.4	29	26	11	
30	23	9		30	26	12	
31	26	11					

Agricultural Engineering Research Center located approximately 2 miles from the field test site. Rain gauges at the test site verified the rainfall data. The field tests were planted the week of May 14, during a very dry period.

The temperature in the greenhouse during the tests fluctuated diurnally and varied with weather conditions. Daytime highs were normally about 30°C with lows at night of about 18°C. The data were recorded with a Bendix Hygro-Thermograph.

Rating Scheme for Evaluating Herbicide Effect

The level of herbicide control of each plant was rated using the following rating schemes. The effect of alachlor on millet was rated using a 1 to 5 scale with

1 a completely dead or missing plant,

2 a plant not completely dead but with little growth,

3 a plant severely stunted but some growth,

4 a plant with evidence of damage, and

5 an undamaged plant.

The effect of atrazine on velvetleaf was rated using a 1 to 3 scale, where

1 was a dead or missing plant,

2 living but showing evidence of damage, and

3 no damage.

Examples of plants exhibiting the rating levels of damage are shown in Figures A2-4 and A2-5 for the millet and velvetleaf respectively.

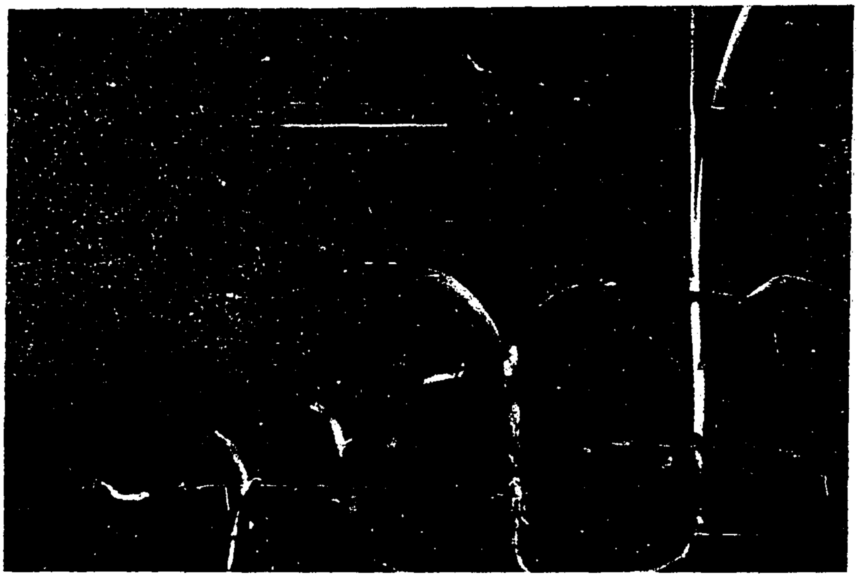


Figure A2-4. Typical plant condition corresponding to ratings of alachlor damage to millet. Rating of 1 on left to 5 on right.

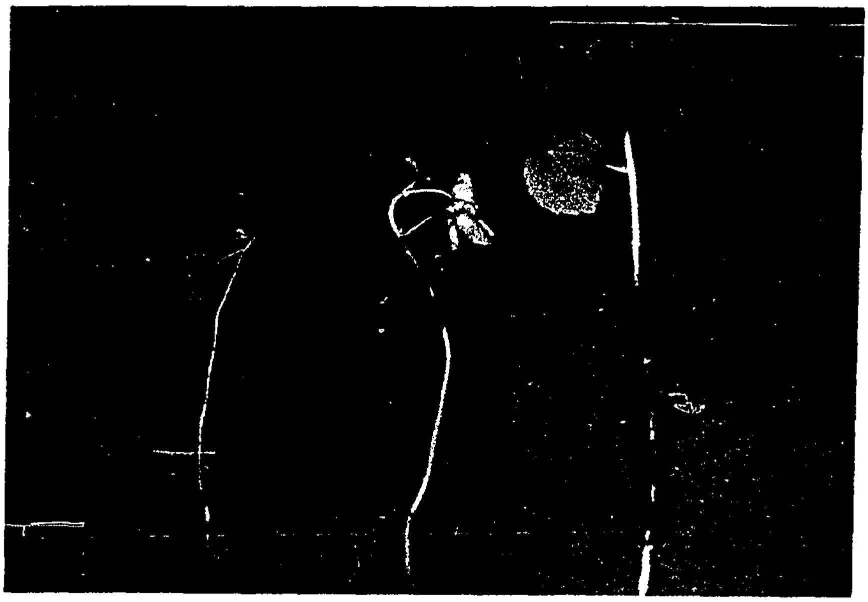


Figure A2-5. Typical plant condition corresponding to ratings of atrazine damage to velvetleaf. Rating of 1 on left to 3 on right.

The ratings were transformed before analysis to a 0 to 1 scale with 1 being complete control and 0 being no control. A control of 0.75, corresponding to a rating of 2 on the millet scale and midway between 1 and 2 on the velvetleaf scale was arbitrarily chosen as acceptable control. A rating of 0.75 indicates control to the extent that the plant is effectively destroyed without overkill.

APPENDIX 3

Position Locator

A position locator (Figure A3-1) was designed, built and used to speed the accurate location of granules distributed on a soil surface and to aid in recording plant ratings. The device, which is hand positioned, has the capability of recording, in three dimensions, the location of a point within a pie-shaped volume with angle of 90°, radius between 13 and 120 cm and thickness of 30 cm.

The location of the position locator probe is indicated by the output of three potentiometers. One indicates the angle of the position locator arm, another the radius, and the third the height of the probe.

A hand operated pushbutton switch initiates the recording cycle. When the probe is in the desired position, the switch is closed and the outputs of the potentiometers are sequentially recorded on both printed and punched paper tape. The recording instrumentation is shown in Figure A3-2. In the upper lefthand corner of the picture is shown a Heath Model EU801 analog digital designer on top of a Dana Model 5403 digital voltmeter. To the right is a CMC Model 410A digital printer. On top of the printer is a constant box used to enter code numbers for experiment and treatment. Beneath the bench on the left is a CMC Model 403A tape perforator adapter which feeds the parallel signal from the DVM serially into the Tally Model P-120 tape perforator (lower right).

A digital circuit to properly time the sequential recording of the three signals was designed and constructed using the analog digital

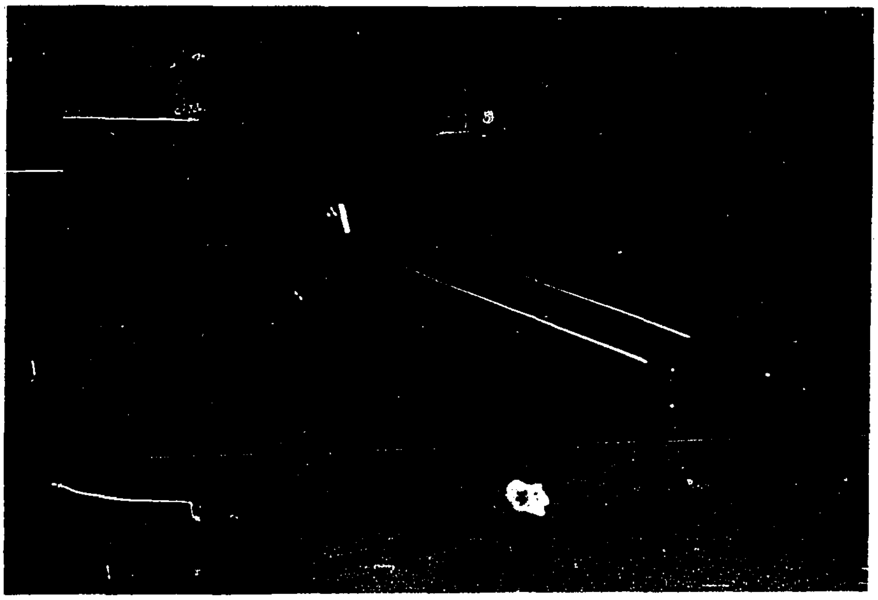


Figure A3-1. Position locator.

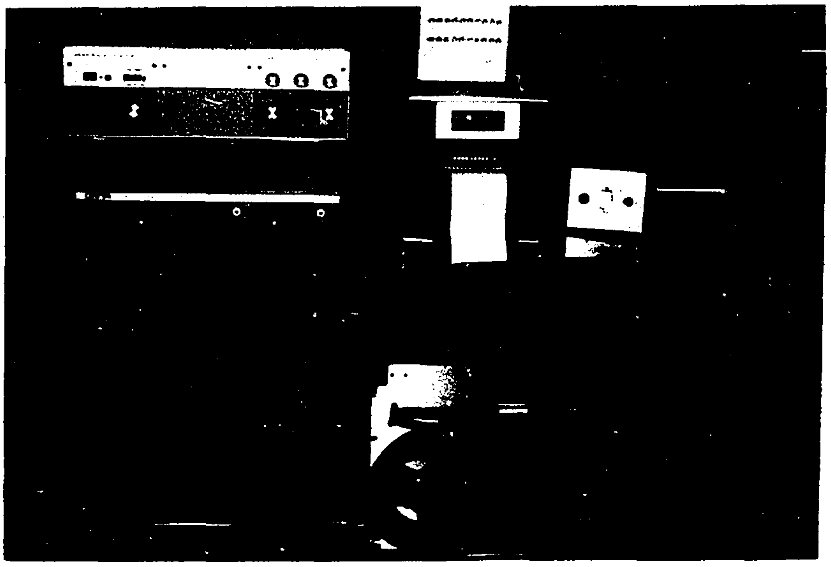


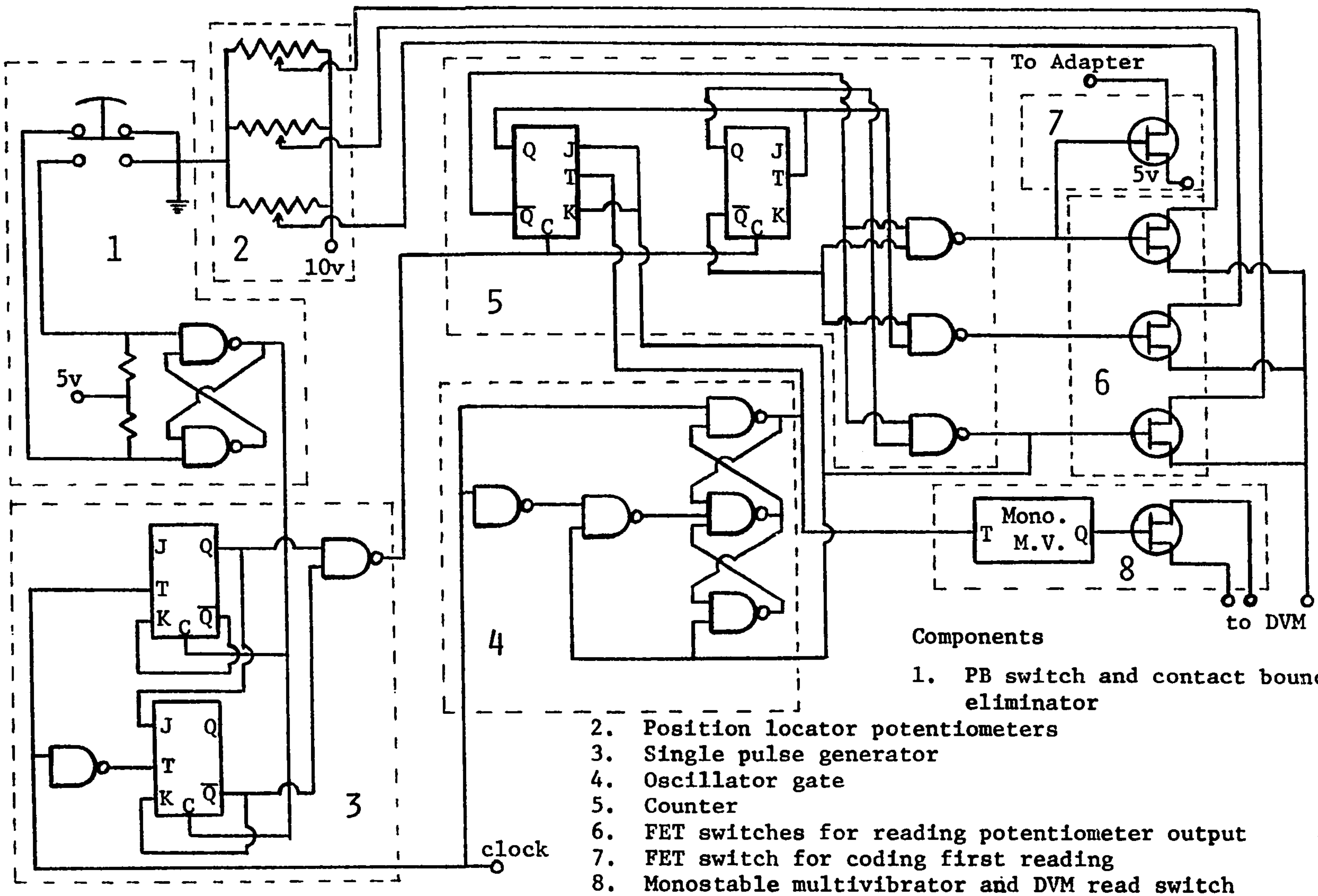
Figure A3-2. Instrumentation for recording data from position locator.

designer and solid state components. The control circuit is shown in Figure A3-3.

The repeatability and linearity of the position locator were evaluated. Ten equispaced points were located on the range of each coordinate. The locations of these points were recorded in random order with 5 replications. The linear correlation coefficients for the lines fit to the data for each coordinate were in every case greater than 0.999. The calibration factors, with 10 volts across the potentiometers, were 0.073 volts/degree for the angle, 0.075 volts/cm for the radius and 0.206 volts/cm for the height.

Four points were then arbitrarily selected. The locations of the points were recorded in random order. This was replicated 4 times. The variance of the readings of each coordinate at each point was determined. These were then pooled to estimate repeatability of the position locator. The 95% confidence intervals about the mean value, for an individual reading were ±0.011 volts for the angle, ±0.006 volts for the radius and ±0.020 volts for the height. These intervals correspond to ±0.15 degrees for the angle (approximately ±0.16 cm at a radius of 60 cm), ±0.08 cm for the radius, and ±0.10 cm for the height.

Before recording a set of data from a test pan, the output of each potentiometer was calibrated by recording the location of two known points for each coordinate. These values were used to check the scale factors. A calibration plate was then placed in the pan and readings at 5 points with a known spatial relationship were made. (Figure A3-4 shows the position locator probe positioned at point 1 on the calibration



Components

1. PB switch and contact bounce eliminator
2. Position locator potentiometers
3. Single pulse generator
4. Oscillator gate
5. Counter
6. FET switches for reading potentiometer output
7. FET switch for coding first reading
8. Monostable multivibrator and DVM read switch

Figure A3-3. Digital circuit to control recording of position locator data.

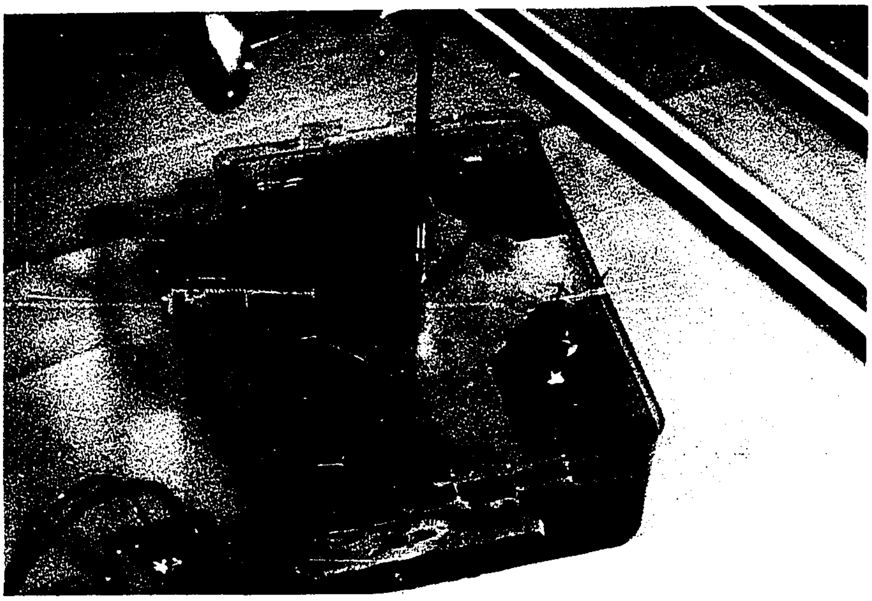


Figure A3-4. Position locator probe at point 1 on calibration plate.

plate.) The values were used to determine the distance and angle through which the points had to be displaced and rotated to align the axes of the pan and the position locator. This calibration procedure was repeated after the desired granule or plant locations had been recorded.

The data were transferred from the punched paper tape to magnetic tape. Conversion was then made from polar to rectangular coordinates which were used in calculating distribution index and control and when plotting data. Plant ratings for control of millet with alachlor for 4 treatments from greenhouse granule distribution test 1 are shown in Figures A3-6, A3-8, A3-10, and A3-12. Photographs of control with the corresponding treatments are shown in Figures A3-5, A3-7, A3-9, and A3-11.

Figure A3-5. Control of millet with alachlor for 8% soil moisture, subirrigation, and granules 1 cm deep in random distribution at density of 0.24 granules/cm. Greenhouse granule distribution test 1.

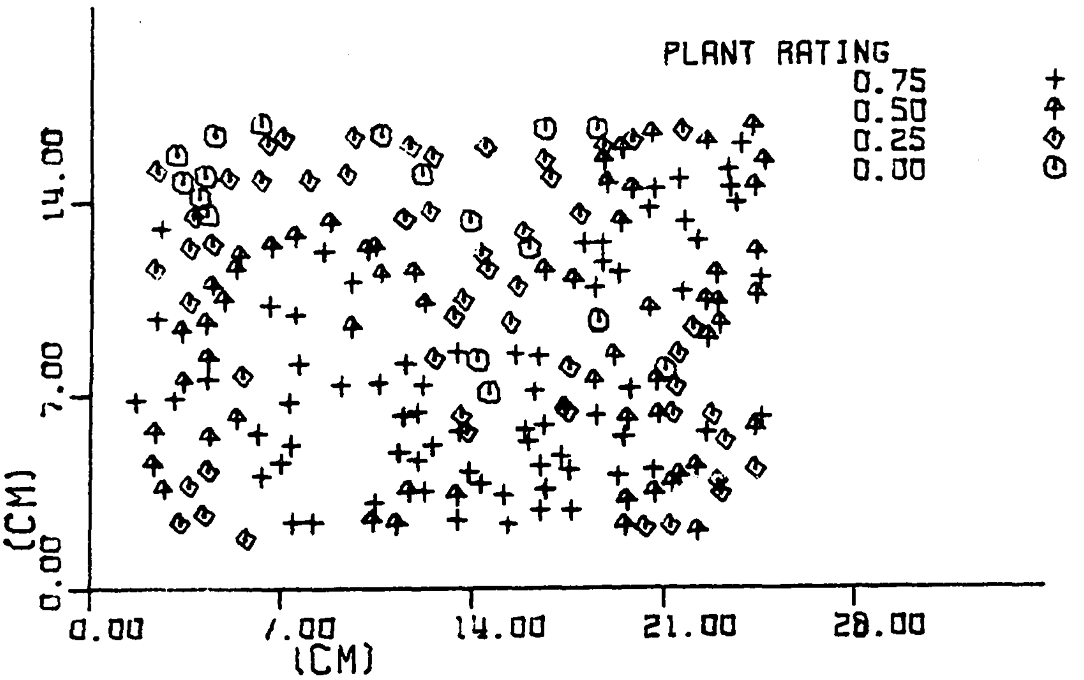


Figure A3-6. Plant ratings for treatment shown in Figure A3-5.

Figure A3-7. Control of millet with alachlor for 15% soil moisture, subirrigation, and granules on surface in hexagonal lattice distribution at density of 0.12 granules/cm. Greenhouse granule distribution test 1.

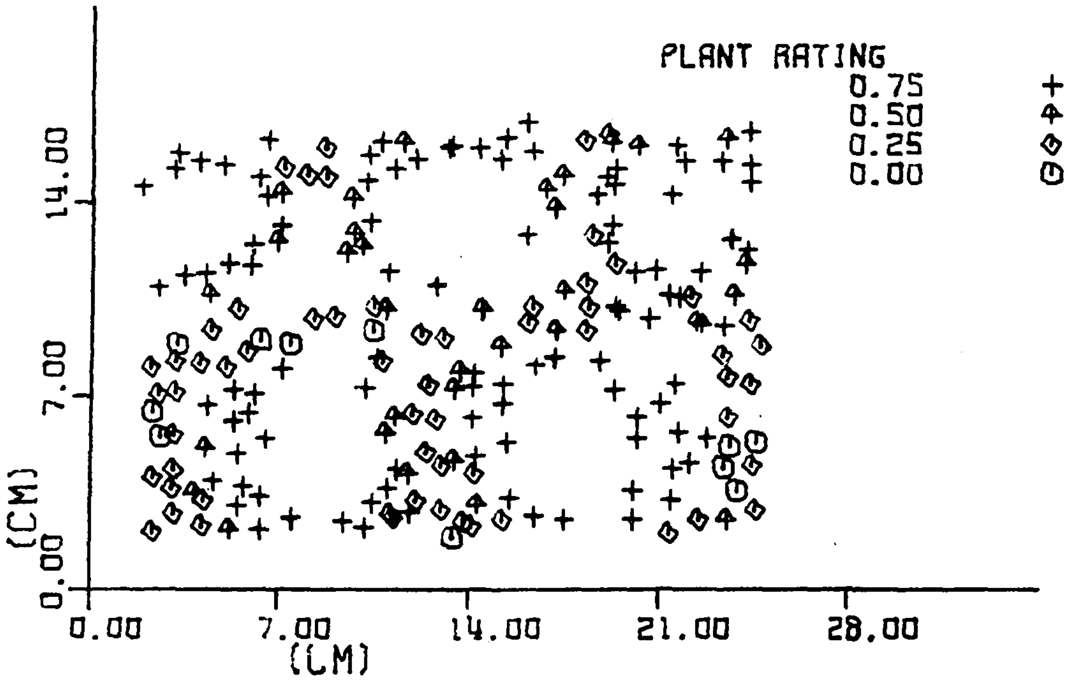


Figure A3-8. Plant ratings for treatment shown in Figure A3-7.

Figure A3-9. Control of millet with alachlor for 15% soil moisture, subirrigation, and granules 1 cm deep in random distribution at density of 0.24 granules/cm. Greenhouse granule distribution test 1.

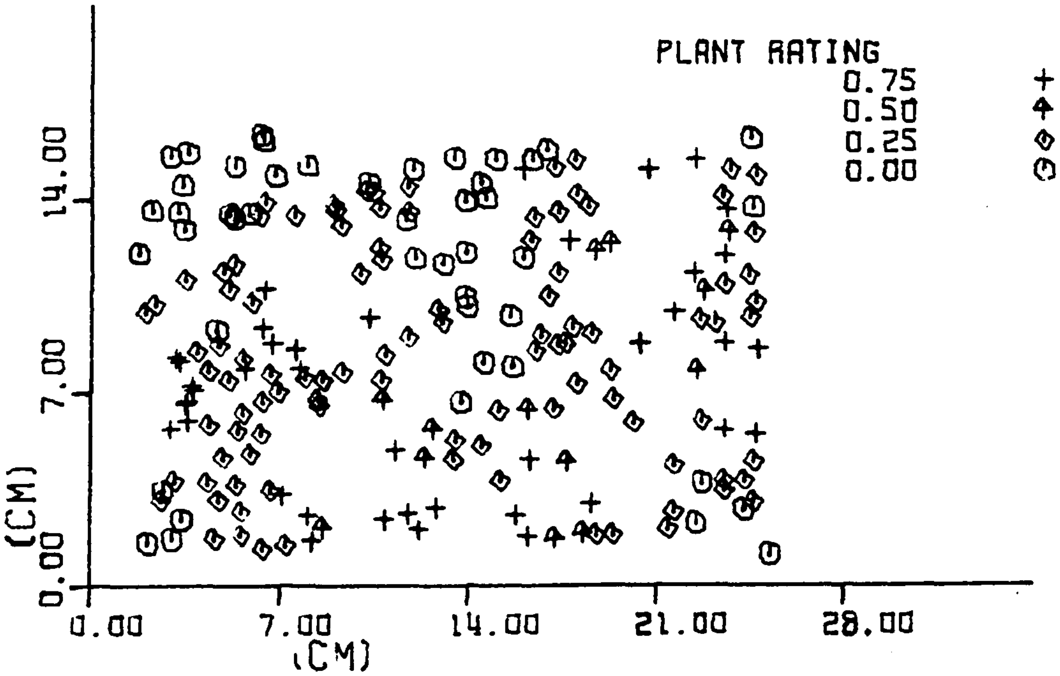


Figure A3-10. Plant ratings for treatment shown in Figure A3-9.

Figure A3-11. Control of millet with alachlor for 15% soil moisture, simulated rain, and granules 1 cm deep in hexagonal lattice distribution at density of 0.12 granules/cm. Greenhouse granule distribution test 1.

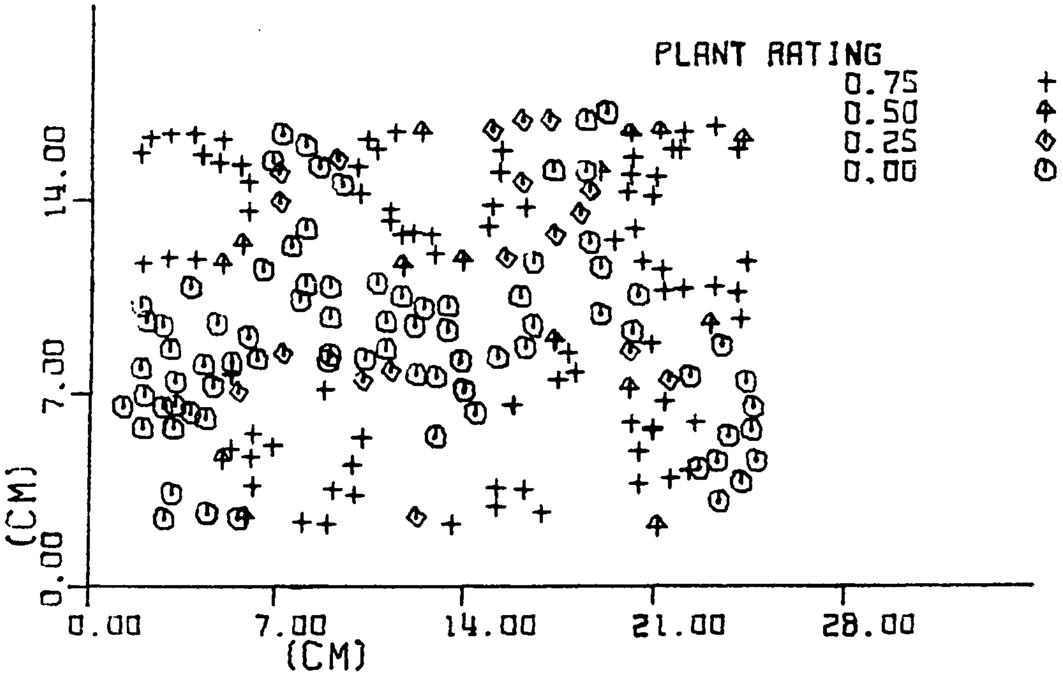


Figure A3-12. Plant ratings for treatment shown in Figure A3-11.

APPENDIX 4

Granule Distributions Investigated

Figures A4-1 through A4-13 show examples of the granule distributions investigated. Plotted on each distribution are a set of random points used in evaluation of the distributions. The granule density (ρ) is 0.10 granules/cm^2 for each distribution.

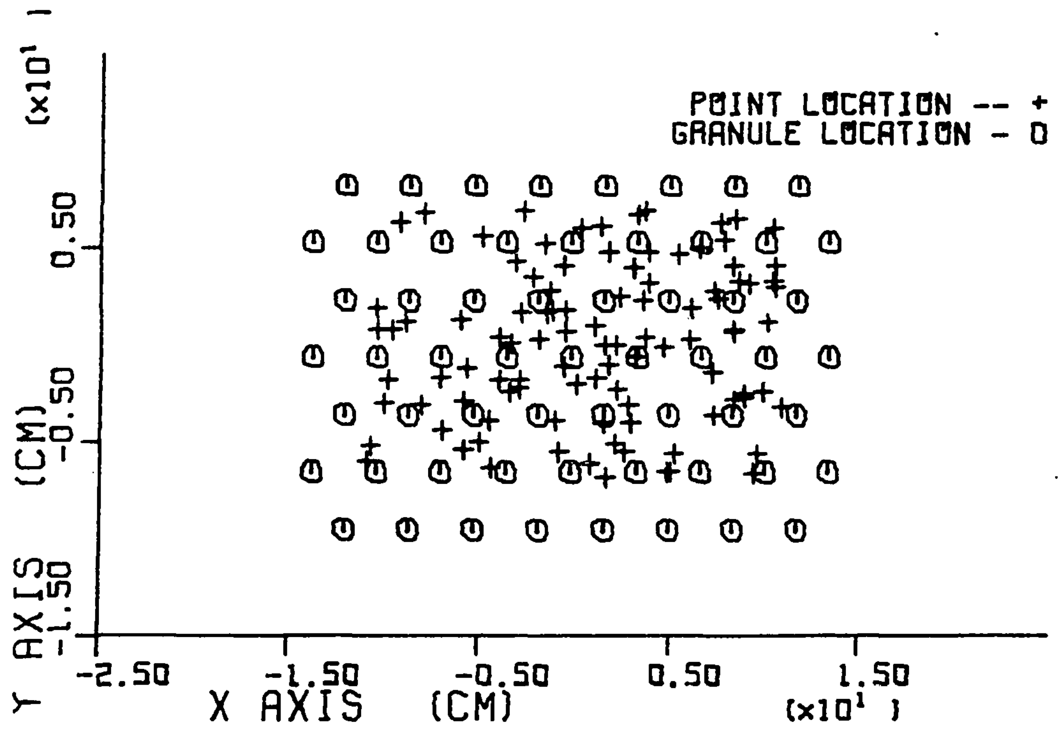


Figure A4-1. Hexagonal lattice distribution.

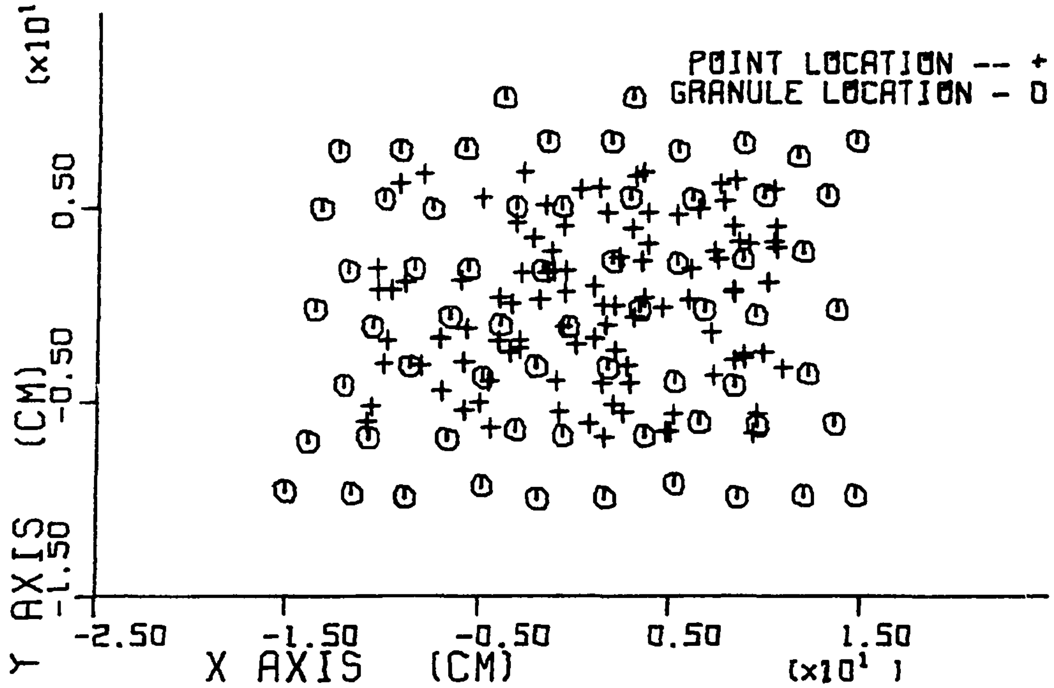


Figure A4-2. Hexagonal lattice distribution with standard deviation of misplacement equal to 0.5 cm.

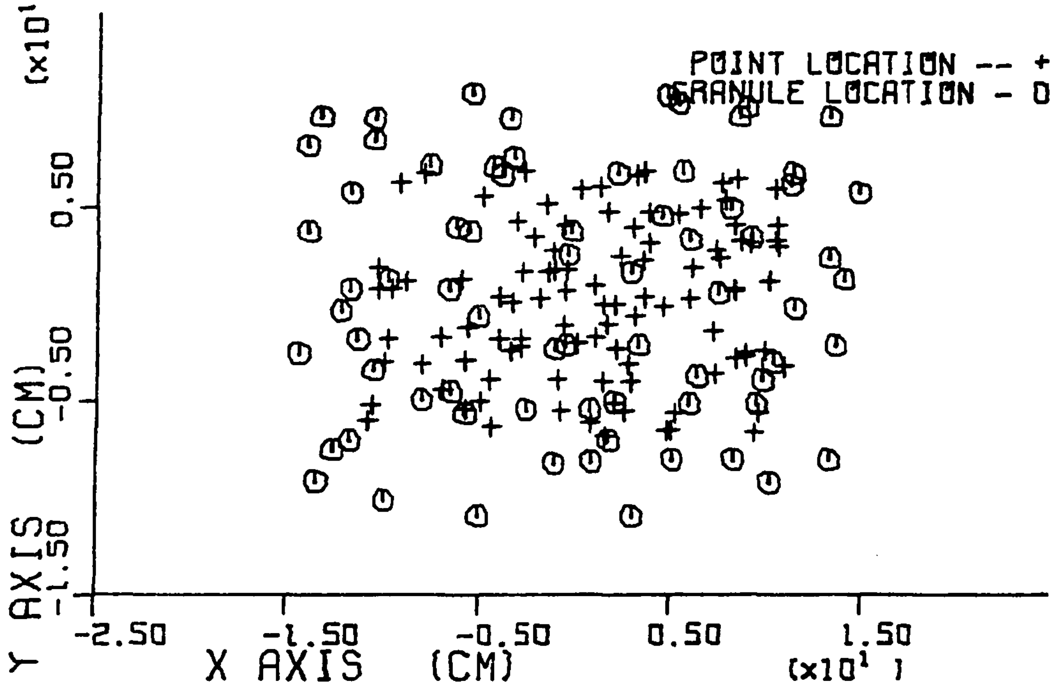


Figure A4-3. Hexagonal lattice distribution with standard deviation of misplacement equal to 1.5 cm.

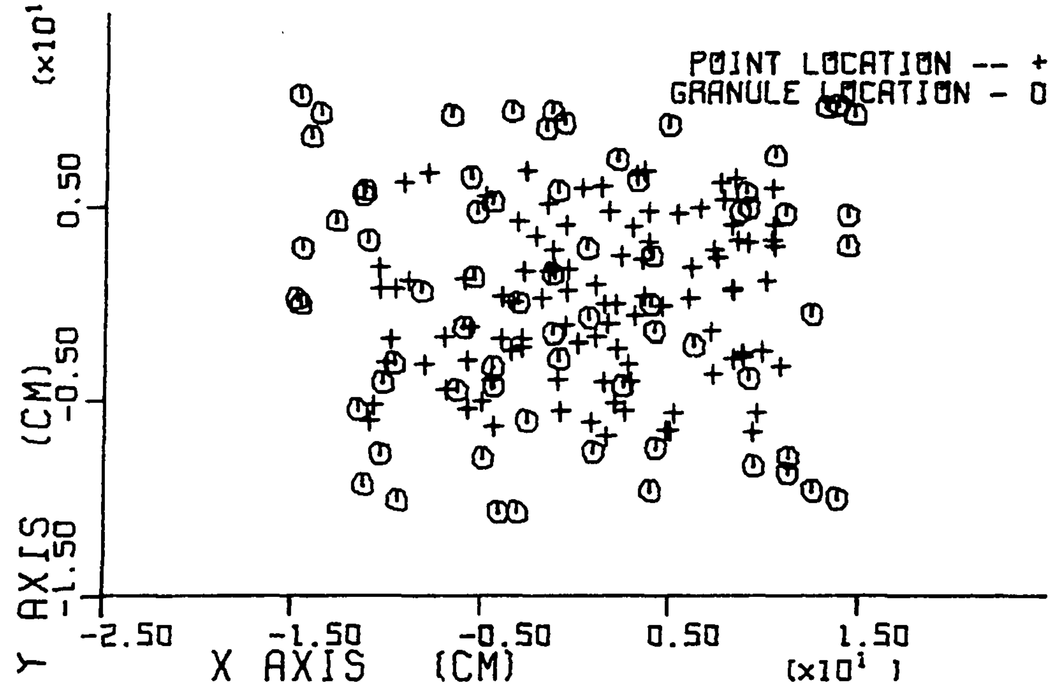


Figure A4-4. Hexagonal lattice distribution with standard deviation of misplacement equal to 2.5 cm.

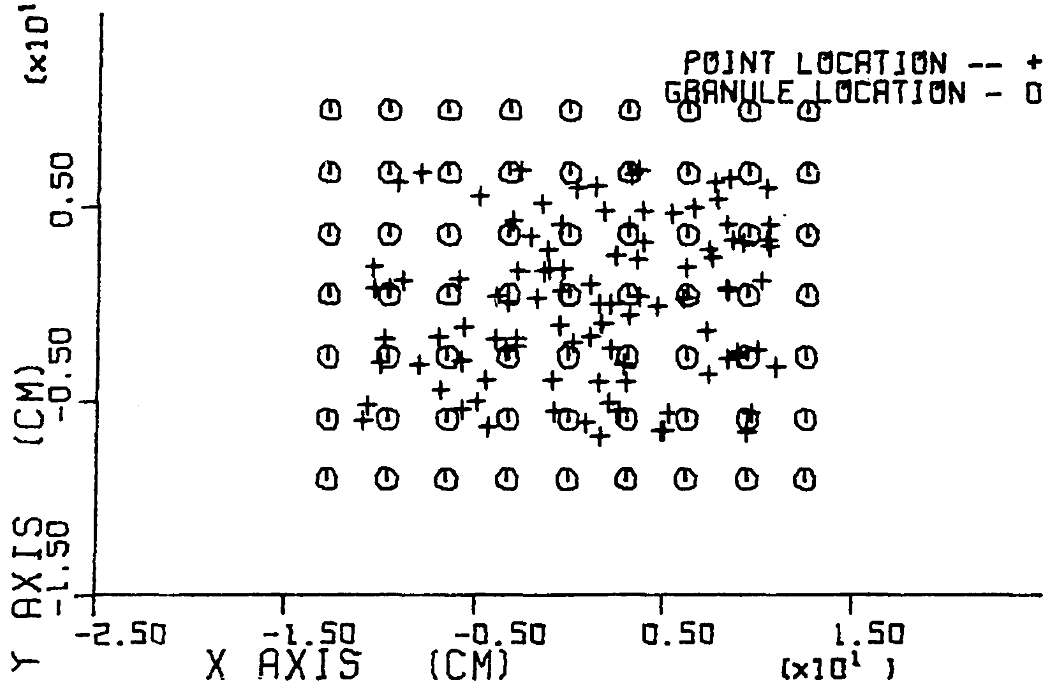


Figure A4-5. Square lattice distribution.

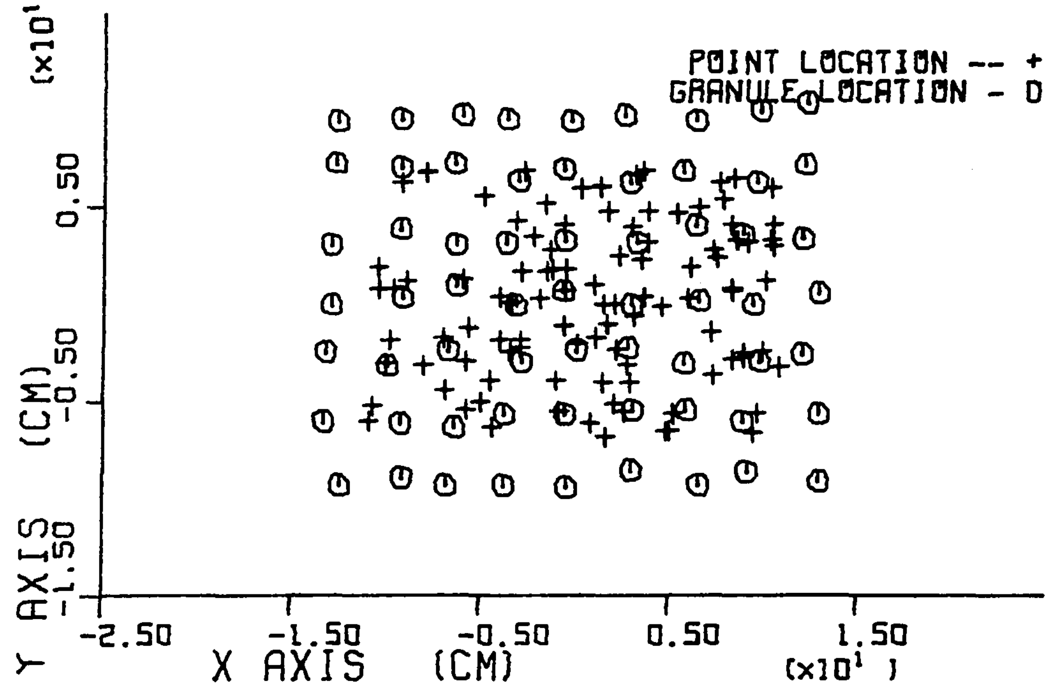


Figure A4-6. Square lattice distribution with standard deviation of misplacement equal to 0.5 cm.

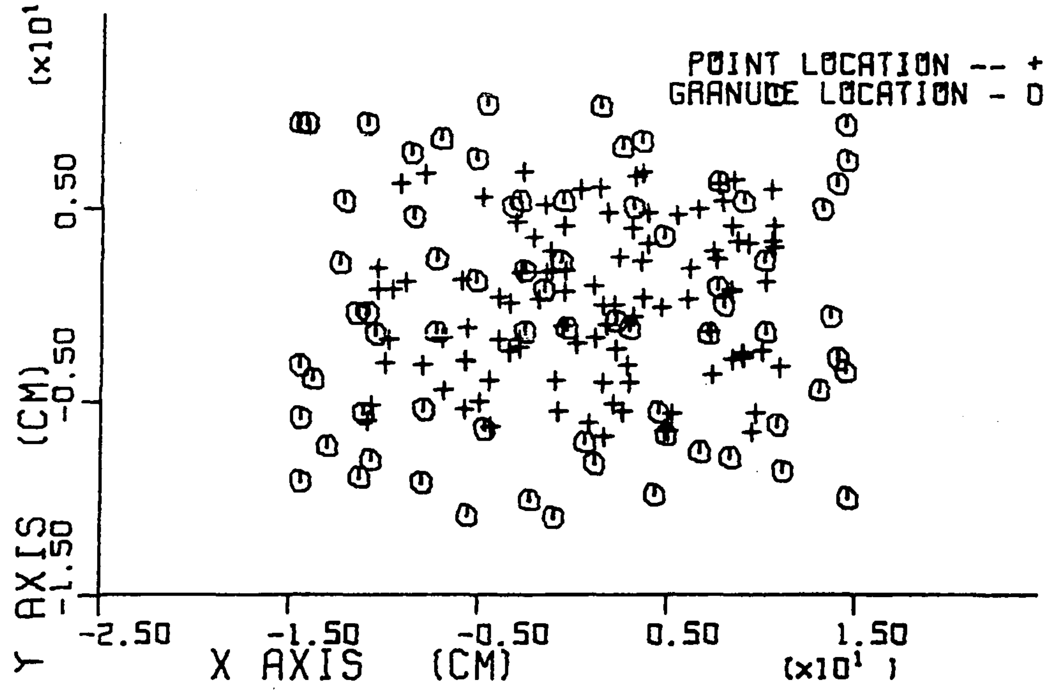


Figure A4-7. Square lattice distribution with standard deviation of misplacement equal to 1.5 cm.

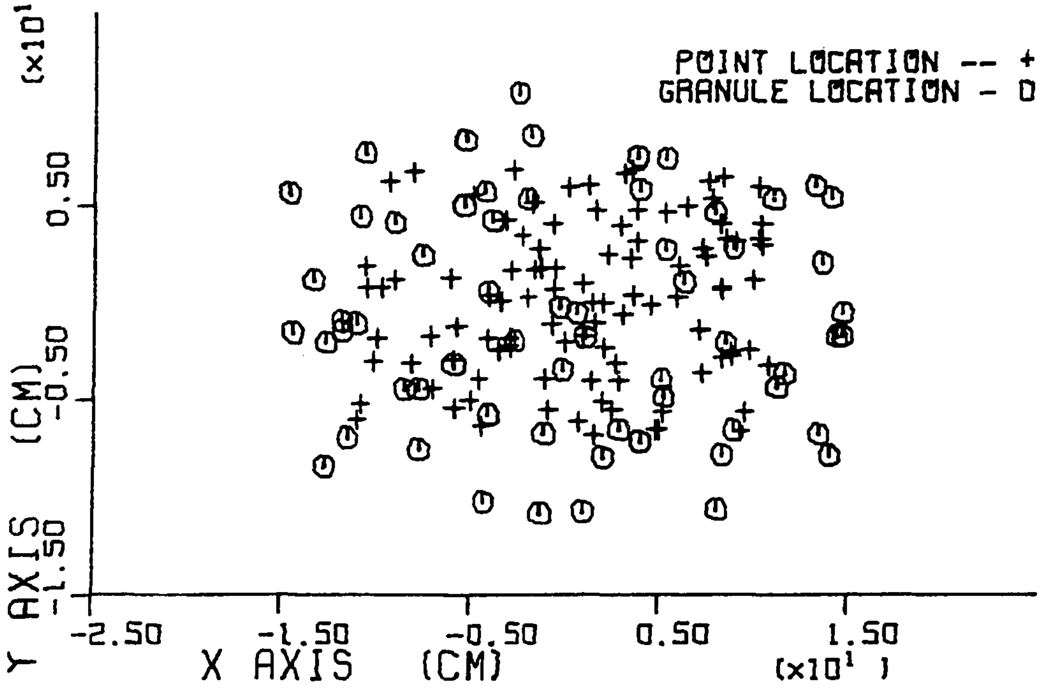


Figure A4-8. Square lattice distribution with standard deviation of misplacement equal to 2.5 cm.

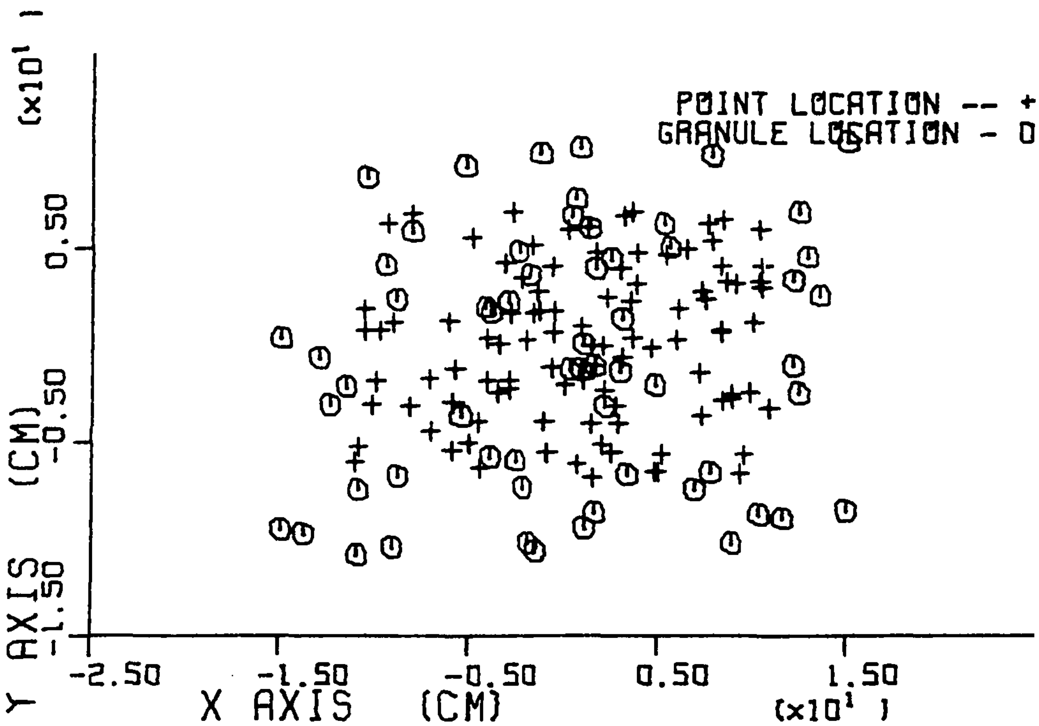


Figure A4-9. Random distribution.

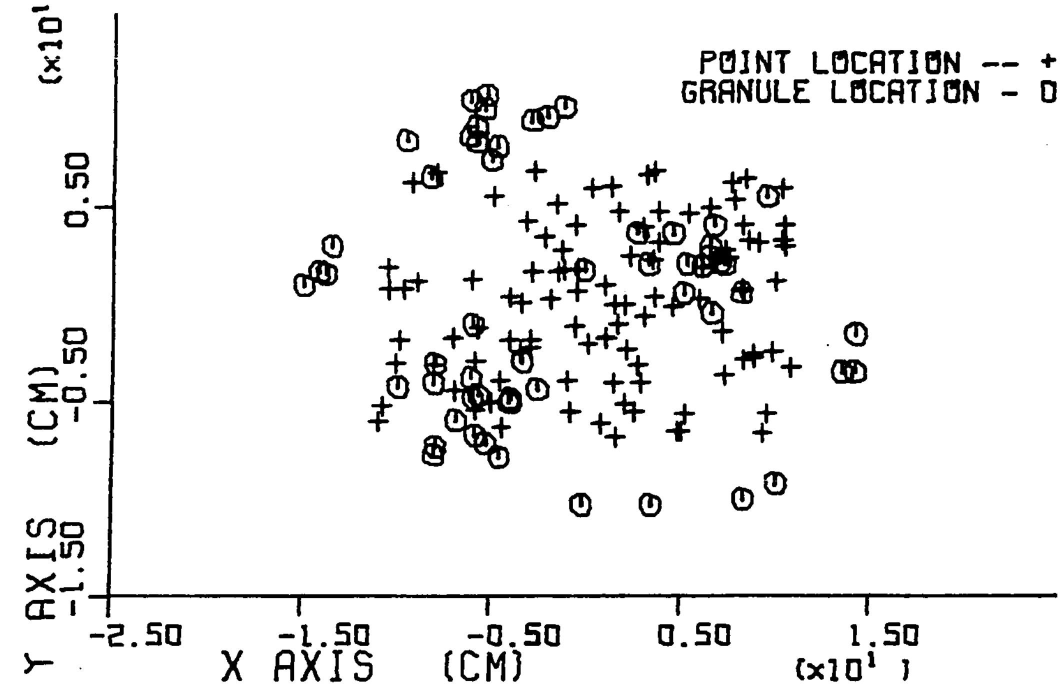


Figure A4-10. Aggregated distribution with 1 circular cluster per 154 cm^2 and standard deviation of dispersion within cluster of 1 cm.

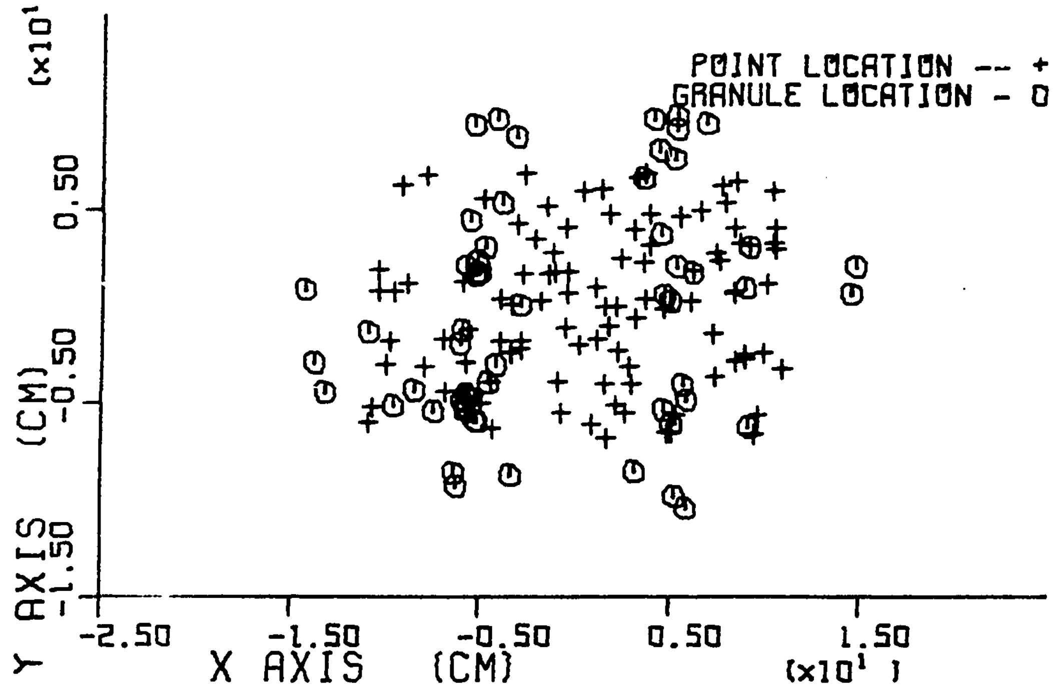


Figure A4-11. Aggregated distribution with 1 circular cluster per 154 cm^2 and standard deviation of dispersion within cluster of 2 cm.

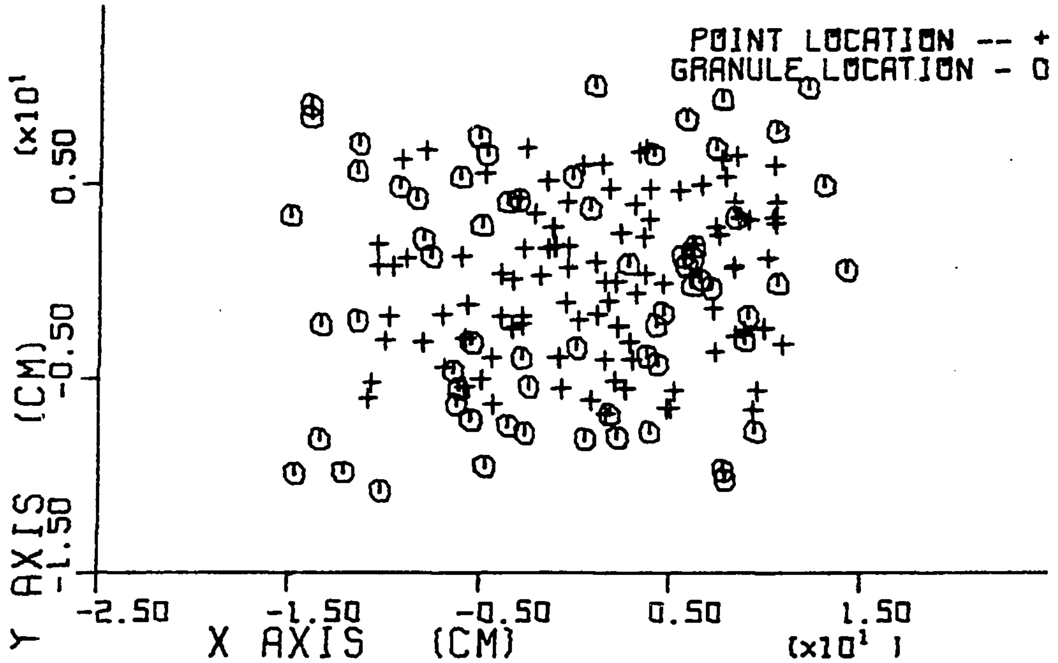


Figure A4-12. Aggregated distribution with 1 linear cluster per 154 cm^2 and standard deviation of dispersion within cluster of 1 cm.

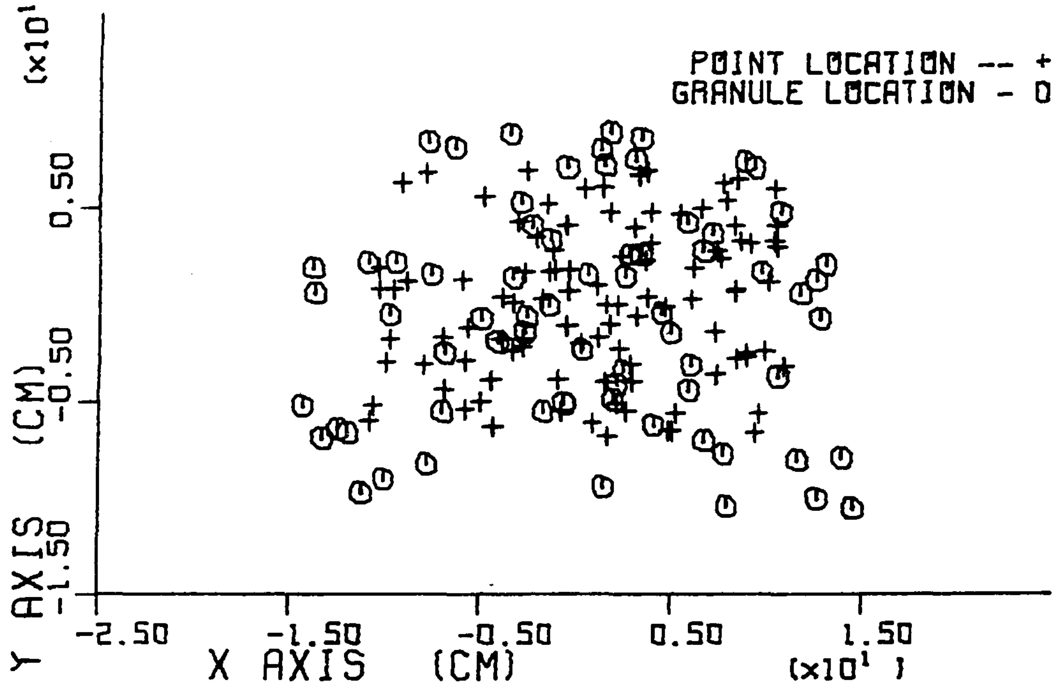


Figure A4-13. Aggregated distribution with 1 linear cluster per 154 cm^2 and standard deviation of dispersion within cluster of 2 cm.

APPENDIX 5

Computer Program to Edit Position Locator Data

PL/1 program to read and edit raw data, one record at a time, from a string of variable length records on magnetic tape.

/* LIST RAW DATA -- PRE-EDIT DATA -- PRINT AND PUNCH EDITED DATA */

```
      /* LIST RAW DATA -- PRE-EDIT DATA -- PRINT AND PUNCH EDITED DATA */
RAWLIST:      PROC OPTIONS (MAIN);
      /* DECLARE ATTRIBUTES OF VARIABLES IN ARRAYS */
              DCL RAW FILE INPUT SEQUENTIAL;
              DCL DISPLAY CHAR (9315) VARYING;
              DCL DISP CHAR (9315);
              DCL SEE(115) CHAR (81) DEFINED DISP;
              DCL EACH (9315) CHAR(1) DEFINED DISP;
              DCL EOW CHAR(1);
              DCL EDSEE (80) CHAR (1);
              DCL EDS CHAR (80) DEFINED EDSEE;
              DCL ED       OUTPUT FILE;
      /* SPECIFY WHAT TO DO AT END OF RAW DATA */
              ON ENDFILE (RAW) GO TO FINISH;
      /* GET READY TO READ RAW DATA */
              OPEN FILE (RAW);
              OPEN FILE(ED) LINESIZE(80);
      /* READ ONE RECORD */
START:        READ FILE (RAW) INTO (DISPLAY);
              DISP=DISPLAY;
      /* DETERMINE LENGHT OF RECORD AND HOW MANY 81 CHARACTER LINES
         NEEDED TO LIST RECORD */
              K=LENGTH (DISPLAY);
              KP=K/81;
              J=MOD (K,81);
              IF J>0 THEN KP=KP+1;
              ELSE;
      /* LIST RAW DATA */
              PUT PAGE;
              PUT EDIT ((SEE(I) DO I=1 TO KP)) (A(81),SKIP) SKIP;
      /* CHECK FOR 9 CHARACTER WORDS (INCLUDING END OF WORD CHARACTER) AND
         ACCUMULATE 9 WORD LINES */
              EOW='-';
```

```
                NWP=0;
               DO JJ=1 TO K;
                IF EACH (JJ)¬=EOW THEN GO TO CONTINUE;
                ELSE;
                JL=JJ-8;
                NWPC=NWP*9+1;
                IF NWP=8  THEN GO TO LWORD;
                ELSE;
              DO JK=NWPC TO NWPC+8;
                EDSEE(JK)=EACH(JL);
OMIT:           JL=JL+1;
              END;
                GO TO ENDCHK;
LWORD:        DO JK=NWPC TO NWPC+7;
                EDSEE(JK)=EACH(JL);
                JL=JL+1;
              END;
                GO TO WRITE;
ENDCHK:         IF JJ=K THEN GO TO WRITE2;
                ELSE;
                NWP=NWP+1;
                GO TO CONTINUE;
      /* LIST 'GOOD' WORDS */
WRITE:          PUT EDIT (EDSEE) ((80)A(1)) SKIP;
      /* PUNCH 'GOOD' WORDS ON CARDS */
                PUT FILE(ED) EDIT (EDSEE) ((80)A(1)) SKIP;
                NWP=0;
CONTINUE:      END;
WRITE2:         PUT EDIT (SUBSTR(EDS,1,NWP*9)) (A(80)) SKIP;
                PUT FILE(ED) EDIT (SUBSTR(EDS,1,NWP*9)) (A(80)) SKIP;
                PUT FILE(ED) SKIP;
                GO TO START;
FINISH:         END RAWLIST;
```

Computer Program to Transform Position Locator Data

Fortran program to transform data from polar coordinates, of position locator, to rectangular coordinates. Data are also edited and plotted.

```
      REAL A(5),R(5),                    X(345),Y(345),TX(345),TY(345),
     & RTX(345),RTY(345),GLAB(2),DATLAB(2)
      REAL*8 ANG(345),RAD(345)
      INTEGER RECODE,TD(1035),PAN
C
C  COMPUTATION OF SCALE FACTORS
C
C  READ VOLTAGES FOR CALIBRATION ANGLES AND RADII
C
  115 CONTINUE
      READ (5,16) DUM
   16 FORMAT (F10.0)
      READ (5,1) CALRA1 ,CALAN2 ,CALRA2 ,CALAN3
    1 FORMAT (13X,F4.3,14X,F4.3,5X,F4.3,14X,F4.3)
C
C  CALCULATION OF RADIUS SCALE FACTOR IN CENTIMETERS PER VOLT
C    FACTOR IS NEGATIVE SINCE VOLTAGE DECREASES AS RADIUS INCREASES
C
      RADSF=30.0/(CALRA2 -CALRA1 )
C
C  CALCULATION OF ANGLE SCALE FACTOR IN DEGREES PER VOLT
C    FACTOR IS POSITIVE (VOLTAGE INCREASES AS ANGLE INCREASES IN
C    CLOCKWISE DIRECTION)
C
      ANGSF=30.0/(CALAN3 -CALAN2 )
C
C  PRINT SCALE FACTORS
C
      WRITE(6,2)ANGSF,RADSF
    2 FORMAT('1  ANGLE SCALE FACTOR =',F8.3,' DEGREES/VOLT',//,
     &       '   RADIUS SCALE FACTOR=',F8.3,' CENTIMETERS/VOLT')
C
C  CALCULATION OF VOLTAGES AT ANGLE=0 AND RADIUS=0
C
      VANGO=CALAN2 -30/ANGSF
      VRADO=CALRA1 -49.5/RADSF
C
```

```
C  PRINT ZERO LEVEL VOLTAGES
C
      WRITE (6,3) VANGO,VRADO
    3 FORMAT(///,'    VOLTAGE AT ANGLE EQUAL ZERO  =',F8.3,' VOLTS',//,
     &            '    VOLTAGE AT RADIUS EQUAL ZERO =',F8.3,' VOLTS')
C
C  COMPUTATION FOR ROTATION AND TRANSLATION OF AXES
C
C   COMPUTATION OF ANGLE OF ROTATION BETWEEN AXES OF PAN AND POSITION
C     LOCATOR
C
C   READ VOLTAGES AND CALCULATE LOCATION OF POINTS ON CALIBRATION PLATE
C
      D=20
      READ (5,4) (A(I),R(I),I=1,5)
    4 FORMAT  (2(4X,F4.3,5X,F4.3,10X),4X,F4.3,5X,F4.3)
      R3=(R(3)-VRADO)*RADSF
      R5=(R(5)-VRADO)*RADSF
      A3=(A(3)-VANGO)*ANGSF
      A5=(A(5)-VANGO)*ANGSF
C
C   CONVERT ANGLES FROM DEGREES TO RADIANS
C
      A3=A3/57.29578
      A5=A5/57.29578
C
C  CALCULATE AND PRINT ANGLE
C
      ALPHA=ARSIN((R5*COS(A5)-R3*COS(A3))/D)
      ALPHA1=ALPHA*57.29578
      WRITE (6,5) ALPHA1
    5 FORMAT (///,'    ANGLE THROUGH WHICH PAN MUST BE ROTATED TO ALINE W
     &ITH AXES OF POSITION LOCATOR',/,20X,'ALPHA=',F5.1)
C
C  CALCULATE AND PRINT X-AXIS AND Y-AXIS TRANSLATION VALUES
C
      R1=(R(1)-VRADO)*RADSF
```

```
      A1=(A(1)-VANGO)*ANGSF
      A1=A1/57.29578
      XTRAN=R1*COS(A1)
      YTRAN=R1*SIN(A1)
      WRITE (6,6) XTRAN,YTRAN
    6 FORMAT(///'   TRANSLATE PAN',F6.2,' CENTIMETERS IN X DIRECTION AND
     &',F6.2,' CENTIMETERS IN Y DIRECTION',/,'  TO MAKE ORIGINS OF AXES
     &OF PAN AND POSITION LOCATOR COINCIDE')
C
C  READ ONE RECORD OF DATA
C
C    READ PAN NUMBER AND RECORD CODE
C
  119 READ(5,7) PAN,RECODE,GLAB,DATLAB
    7 FORMAT(2I5,2(2X,2A4))
C
C    READ DATA INTO TEMPORARY DATA SET UNTIL END OF RECORD SYMBOL IS
C   FOUND
C
      J=1
    8 FORMAT (8(I8,1X),I8)
  101 J8=J+8
      READ (5,8) (TD(I),I=J,J8)
      IF(TD(J).EQ.99999999) GO TO 100
      J=J+9
      GO TO 101
C
C EDIT BLANKS FROM TEMPORARY DATA SET AND CHECK FOR SEQUENCE
C
C    K EQUALS NUMBER OF WORDS IN TEMPORARY DATA SET
C
  100 K=J-1
      IF(K.EQ.0) GO TO 114
      GO TO 120
  114 IF(RECODE.NE.5) GO TO 119
      GO TO 115
  120 CONTINUE
```

```
      KK=1
      JJ=1
      DO 102 I=1,K
      IF(TD(I).EQ.0) GO TO 102
      M=KK/3
      N=3*M
      MOD=KK-N
      ID=TD(I)/10000
      IDM=ID/100
      IDN=100*IDM
      IDMOD=ID-IDN
      IF(MOD.EQ.1) GO TO 103
      IF(MOD.EQ.2) GO TO 105
      IF(MOD.EQ.0) GO TO 106
  103 IF(IDMOD.NE.10) GO TO 104
      ANG(JJ)=TD(I)
      ANG(JJ)=ANG(JJ)/1000.
      GO TO 106
  105 IF(IDMOD.NE.0) GO TO 107
      RAD(JJ)=TD(I)
      RAD(JJ)=RAD(JJ)/1000.
      JJ=JJ+1
  106 KK=KK+1
  102 CONTINUE
      GO TO 113
C
C  ERROR MESSAGE PRINTED FOR IMPROPER IDENTIFICATION OF ANGLE VALUE
C
  104 WRITE (6,9) IDMOD,TD(I),I
    9 FORMAT(///' IMPROPER IDENTIFICATION OF ANGLE VALUE',/,
     &       '    IDMOD=',I5,'  TD(I)=',I8,'    I=',I5)
      GO TO 114
C
C  ERROR MESSAGE PRINTED FOR IMPROPER IDENTIFICATION OF RADIUS VALUE
C
  107 WRITE (6,10) IDMOD,TD(I),I
   10 FORMAT (///'    IMPROPER IDENTIFICATION OF RADIUS VALUE',/,
```

```
     &        '    IDMOD=',I5,'  TD(I)=',I8,'    I=',I5)
      GO TO 114
C
C  LIST EDITED RECORD
C
  113 CONTINUE
      WRITE (6,11) PAN,RECODE
   11 FORMAT('1',///,'    PAN NUMBER =',I5,'     RECORD CODE NUMBER =',
     &        I5,///,10X,  'ANGLE',10X,'RADIUS')
      JJ=JJ-1
      DO 109 I=1,JJ
  109 WRITE(6,12) I,ANG(I),RAD(I)
   12 FORMAT(2X,I5,1X,F9.3,7X,F9.3)
C
C  CONVERSICN FROM POLAR TO RECTILINEAR COORDINATES
C
      DO 110 I=1,JJ
      IANG=ANG(I) *1000
      IAN=IANG/10000
      IA=IAN*10000
      VANG=IANG-IA
      VANG=VANG/1000
      BETA=(VANG-VANGO)*ANGSF
      BETA=BETA/57.29578
      IRAD=RAD(I) *1000
      IRA=IRAD/10000
      IR=IRA*10000
      VRAD=IRAD-IR
      VRAD=VRAD/1000
      RADIUS=(VRAD-VRADO)*RADSF
      X(I) =RADIUS*COS(BETA)
  110 Y(I) =RADIUS*SIN(BETA)
C
C  TRANSLATION OF AXES
C
      DO 111 I=1,JJ
      TX(I) =X(I) -XTRAN
```

```
  111 TY(I) =Y(I) -YTRAN
C
C  ROTATION OF AXES
C
      CA=COS(ALPHA)
      SA=SIN(ALPHA)
      DO 112 I=1,JJ
      RTX(I) =TX(I) *CA-TY(I) *SA
      RTY(I)= TX(I) *SA+TY(I) *CA
      RTX(I)=-RTX(I)+9.5
      RTY(I)=-RTY(I)+13.25
  112 CONTINUE
C
C  PRINT NEW COORDINATES
C
      WRITE (6,13) PAN,RECODE,JJ
   13 FORMAT(' ',///'     PAN NUMBER =',I5,'      RECORD CODE NUMBER =',
     &       I5,'     NUMBER OF OBSERVATIONS IN RECORD=',I5)
      WRITE (6,14)
   14 FORMAT      (///,5X,4('X-COORDINATE   Y-COORDINATE    '))
      WRITE (6,15) (RTX(I),RTY(I),I=1,JJ)
   15 FORMAT(4(5X,F10.3,5X,F10.3))
C
C  PUNCH NEW COORDINATES
      WRITE (7,17) PAN,RECODE,JJ
   17 FORMAT (3I5)
      WRITE (7,26) (RTX(I),RTY(I),I=1,JJ)
   26 FORMAT (8(F8.2,2X))
C
C
C   PLOT LOCATIONS OF PLANTS
C
      IF(RECODE.NE.2) GO TO 116
      CALL GRAPH (JJ,RTY,RTX,3,107,5.0,3.0,7.0,0.0,7.0,0.0,
     &'   (CM);','    (CM);','PLANT RATING;','             0.75;')
      GO TO 119
  116 IF(RECODE.NE.3) GO TO 117
```

```
      CALL GRAPHS (JJ,RTY,RTX,6,107,'                  0.50;')
      GO TO 119
  117 IF(RECODE.NE.4) GO TO 118
      CALL GRAPHS (JJ,RTY,RTX,5,107,'                  0.25;')
      GO TO 119
  118 CALL GRAPHS (JJ,RTY,RTX,1,107,'                  0.00;')
      GO TO 115
      STOP
      END
```

Computer Program to Evaluate Granule Distributions

Fortran program to generate random points, generate granule distributions and compute for each distribution the distribution index, coverage, distribution efficiency, and distribution adequacy.

```
C           PROGRAM TO GENERATE COORDINATES OF RANDOM POINTS, CALCULATE
C       DISTANCES FROM RANDOMLY SELECTED POINTS TO NEAREST GRANULE,
C       CALCULATE DISTRIBUTION INDEX, AND CALCULATE PREDICTED CONTROL AS
C       FUNCTION OF ROI FOR GIVEN GRANULE DISTRIBUTION.
C
C
C             INPUT:
C                     STARTING VALUE FOR GENERATION OF RANDOM POINTS (IX)
C                        VALUE MUST BE ODD
C                      AND NUMBER OF RANDOM POINTS TO GENERATE (NRP)
C                        FORMAT(I9,6X,I5)
C                     DISTRIBUTION   (DIST)
C                       FORMAT (3A4)
C                    (RANDOM,SQUARE,HEXAGONAL,AGGREGATED,OR EXPERIMENTAL)
C
C
C
      DATA RDIST/4HRAND/,QDIST/4HSQUA/,HDIST/4HHEXA/,END/4HENDO/
     &,REPEAT/4HREPE/,EDIST/4HEXPE/,ADIST/4HAGGR/
          REAL XR(1000),YR(1000),XG(1000),YG(1000),D(1000),SDIST(100)
     &,ROI(10)              ,XNOVLP(10),XNROI(10),DIST(3),XNSROI(10,5)
     &,DISEFF(10,5),ADQAPP(10,5),Y(10),XGR(99),YGR(99)
     &,XC(4),YC(4)
      INTEGER CONT(10),NROI(10),NSROI(10),NOVLP(10)
C
C  GENERATE NRP  RANDOM COORDINATES  (NRP LE  1000)
C
  402 CONTINUE
      READ (5,1) IX,NRP
    1 FORMAT (I9,6X,I5)
      WRITE(6,1004) IX
 1004 FORMAT(10X,'IX=',I9)
      DO 103 I=1,NRP
      CALL RANDU (IX,IY,YFL)
      IX=IY
  103 XR(I)=YFL*22.0-11.0
      DO 104 I=1,NRP
      CALL RANDU (IX,IY,YFL)
```

```
      IX=IY
  104 YR(I)=YFL*14.0-7.0
C
C    COMPUTATIONS FOR EACH DATA SET
C
C
C   GENERATE REFERENCE POINT FOR ALIGNING GRANULES ON TEST AREA
C
      CALL RANDU (IX,IY,YFL)
      IX=IY
      XGREF=YFL*10.0-25.0
      CALL RANDU (IX,IY,YFL)
      IX=IY
      YGREF=YFL*4.0-15.0
      WRITE(6,1003) XGREF,YGREF
 1003 FORMAT(10X,'XGREF=',F10.3,5X,'YGREF=',F10.3)
      XGREF=-XGREF
      YGREF=-YGREF
C
C   GENERATE GRANULE COORDINATES
C
  116 CONTINUE
      READ (5,40) RADM
   40 FORMAT (F5.2)
      READ (5,2) DIST
    2 FORMAT (3A4)
      IF(DIST(1).EQ.END) GO TO 100
      IF(DIST(1).EQ.REPEAT) GO TO 402
      WRITE (6,4) DIST
    4 FORMAT('1',10X,3A4)
      I=1
      RHO=0.20
      DO 107 I=1,5
      RHO=RHO+0.02
      NG=RHO*1232
      IF(DIST(1).EQ.RDIST) GO TO 301
      IF(DIST(1).EQ.QDIST) GO TO 302
```

```
      IF(DIST(1).EQ.HDIST) GO TO 303
      IF(DIST(1).EQ.EDIST) GO TO 304
      IF(DIST(1).EQ.ADIST) GO TO 308
C
C        RANDOM GRANULE SPACING
C
  301 CONTINUE
      DO 108 J=1,NG
      CALL RANDU (IX,IY,YFL)
      IX=IY
  108 XG(J)=YFL*44.0-XGREF
      DO 109 J=1,NG
      CALLRANDU (IX,IY,YFL)
      IX=IY
  109 YG(J)=YFL*28.0-YGREF
      GO TO 401
C
C        SQUARE LATTICE SPACING
C
  302 CONTINUE
      SPX=SQRT(1/RHO)
      SPY=SPX
      NXG=(44/SPX)+1
      NYG=(28/SPY)+1
      NG=0
      DO 120 II=1,NYG
      DO 120 IJ=1,NXG
      NG=NG+1
      XG(NG)=SPX*(IJ-1)-XGREF
  120 YG(NG)=SPY*(II-1)-YGREF
      GO TO 401
C
C        HEXAGONAL LATTICE SPACING
C
  303 CONTINUE
      Z=SQRT(1/(RHO*2.598))
      SPX=1.732*Z
```

```
      SPY=1.5*Z
      NXG=(44/SPX)+1
      NYG=(30/SPY)+1
      NYG2=NYG/2
      NG=0
      DO 121 IK=1,NYG2
      DO 122 IJ=1,NXG
      II=2*IK-1
      NG=NG+1
      XG(NG)=SPX*(IJ-1)-XGREF
  122 YG(NG)=SPY*(II-1)-YGREF
      DO 121 IJ=1,NXG
      II=2*IK
      NG=NG+1
      XG(NG)=SPX*(IJ-1)+0.5*SPX-XGREF
  121 YG(NG)=SPY*(II-1)-YGREF
      GO TO 401
C
C         AGGREGATED DISTRIBUTION
C
  308 CONTINUE
      READ (5,500) NGROUP,NTYPE
C  NTYPE EQUAL 1 FOR CLUSTERS AND EQUAL 2 FOR ROWS
  500 FORMAT (2I5)
      IF(NTYPE.EQ.1) NG=RHO*924
      READ (5,513)AM,S
  513 FORMAT (2F10.4)
      IF(NTYPE.EQ.2) GO TO 501
      XGR(1)=-5.5
      YGR(1)=-3.5
      XGR(2)= 5.5
      YGR(2)= 3.5
      XGR(3)= 5.5
      YGR(3)=-10.5
      XGR(4)=-5.5
      YGR(4)= 10.5
      XGR(5)= 16.5
```

```
      YGR(5)=-3.5
      XGR(6)=-16.5
      YGR(6)= 3.5
      XGR(7)= 5.5
      YGR(7)=-3.5
      XGR(8)=-5.5
      YGR(8)= 3.5
      XGR(9)=-16.5
      YGR(9)=-3.5
      XGR(10)=-5.5
      YGR(10)=-10.5
      XGR(11)=16.5
      YGR(11)= 3.5
      XGR(12)=5.5
      YGR(12)=10.5
      NGE=NG/NGROUP
      DO 505 IGR=1,NGE
      DO 505 INGR=1,NGROUP
      NGR=(INGR-1)*NGE+IGR
      XG(NGR)=XGR(INGR)
  505 YG(NGR)=YGR(INGR)
      IF( NGR.GE.NG) GO TO 510
  506 NGR=NGR+1
      XG(NGR)=XGR(1)
      YG(NGR)=YGR(1)
      IF(NGR.LT.NG) GO TO 506
      GO TO 510
  501 CONTINUE
      XGR(1)=-2.75
      XGR(2)= 8.25
      XGR(3)=-13.75
      XGR(4)= 2.75
      XGR(5)=13.75
      XGR(6)=-8.25
      NGE=NG/NGROUP
      DO 509 IGR=1,NGE
      DO 509 INGR=1,NGROUP
```

```
      NGR=(INGR-1)*NGE+IGR
  509 XG(NGR)=XGR(INGR)
      IF(NGR.GE.NG) GO TO 512
  511 NGR=NGR+1
      XG(NGR)=XGR(INGR)
      IF(NGR.LT.NG) GO TO 511
      GO TO 512
  510 CONTINUE
      DO 514 IG=1,NG
      CALL RANDU (IX,IY,YFL)
      IX=IY
      ANG=6.2832*YFL
      CALL GAUSS (IX,S,AM,V)
      V=ABS(V)
      XGM=V*COS(ANG)
      YGM=V*SIN(ANG)
      XG(IG)=XG(IG)+XGM
      YG(IG)=YG(IG)+YGM
  514 CONTINUE
      GO TO 401
  512 CONTINUE
      DO 515 IG=1,NG
      CALL RANDU (IX,IY,YFL)
      IX=IY
      YG(IG)=YFL*24-12
      CALL GAUSS (IX,S,AM,V)
      XG(IG)=XG(IG)+V
  515 CONTINUE
      GO TO 401
C
C           EXPERIMENTAL DISTRIBUTION
C
  304 CONTINUE
      READ (5,307)  NG
  307 FORMAT(I5)
      DO 306 ING=1,NG
      READ(5,305) YG(ING),XG(ING)
```

```
      YG(ING)=YG(ING)-7.0
      XG(ING)=XG(ING)-11.0
  306 CONTINUE
  305 FORMAT (2F10.2)
      RHO=NG/468.0
  401 CONTINUE
C
C  CALCULATE NEW GRANULE COORDINATES INCLUDING FACTOR FOR MISPLACEMENT
C
      WRITE (6,1001) NG,RHO,NGROUP,NTYPE,AM,S
 1001 FORMAT (10X,'NG=',I8,'  GRANULE DENSITY=',F5.2,'GRANULES/SQ.CM'
     &,5X,I5,2X,'GROUPS',5X,'TYPE',I5,5X,'MEAN',F5.2,5X,'STAND. DEV.',
     &F5.2)
      DO 41 IG=1,NG
      CALL RANDU (IX,IY,YFL)
      IX=IY
      RAD=RADM*YFL
      CALL RANDU (IX,IY,YFL)
      IX=IY
      ANG=6.2832*YFL
      XGM=RAD*COS(ANG)
      YGM=RAD*SIN(ANG)
      XG(IG)=XG(IG)+XGM
      YG(IG)=YG(IG)+YGM
   41 CONTINUE
C
C  PLOT POINT AND GRANULE LOCATIONS
C
      CALL GRAPH (NRP,XR,YR,3,7,5.0,3.0,10.0,-25.0,10.0,-15.0,
     &'X AXIS  (CM);','Y AXIS  (CM);',' POINT LOCATION -- +;',
     &           'GRANULE LOCATION - O;')
      CALL GRAPHS (NG,XG,YG,1,7,';')
C
C  CALCULATE DISTANCE FROM POINT TO NEAREST GRANULE
C
      DO 111 JJ=1,10
      RJJ=JJ
```

```
      ROI(JJ)=RJJ/2
      NSROI(JJ)=0
  111 NROI(JJ)=0
      SDIST(1)=100.0
      DO 113 KR=1,NRP
      DO 101 K =1,NG
      D(K) =SQRT((XR(KR)-XG(K))**2+(YR(KR)-YG(K))**2)
      DO 110 JK=1,10
      JJ=11-JK
      IF(D(K).GT.ROI(JJ)) GO TO 117
      NROI(JJ)=NROI(JJ)+1
  110 CONTINUE
  117 CONTINUE
      IF(K.EQ.1) GO TO 106
      IF(D(K).GE.SDIST(KR)) GO TO 101
  106 SDIST(KR)=D(K)
  101 CONTINUE
      DO 114 JJ=1,10
  114 IF(SDIST(KR).LE.ROI(JJ)) NSROI(JJ)=NSROI(JJ)+1
  113 CONTINUE
      WRITE (6,6) SDIST
    6 FORMAT(10F10.3)
C
C  CALCULATE AVERAGE SQUARED SHORTEST DISTANCE
C
      SSQSD=0
      DO 127 ISDIST=1,NRP
  127 SSQSD=SSQSD+SDIST(ISDIST)**2
      RSQAV=SSQSD/NRP
C
C  CALCULATE DISTRIBUTION INDEX
C
      ALPHA=RHO*3.1416*RSQAV
      WRITE(6,128) SSQSD,RSQAV,ALPHA
  128 FORMAT('SUM OF SQUARES',F10.2,/,'AVERAGE SHORTEST DISTANCE SQUARED
     &',F10.3,/,'ALPHA',F10.4)
      DO 112 JJ=1,10
```

```
112 NOVLP(JJ)=NROI(JJ)-NSROI(JJ)
    DO 115 JJ=1,10
    XNROI(JJ)=NROI(JJ)
    XNSROI(JJ,I)=NSROI(JJ)
    XNOVLP(JJ)=NOVLP(JJ)
    IF(XNROI(JJ).EQ.0) XNROI(JJ)=1
    DISEFF(JJ,I)=(XNSROI(JJ,I)/XNROI(JJ))
    ADQAPP(JJ,I)=(DISEFF(JJ,I)*XNSROI(JJ,I))/NRP
115 CONTINUE
    WRITE(6,13)
 13 FORMAT(/,12X,'ROI',10X,'COVERAGE',2X,'OVERLAP',2X,
   &'DISPERSION EFFICIENCY',2X,'ADEQUACY OF APPLICATION',/)
    DO 1112 JJ=1,10
1112 WRITE (6,10) ROI(JJ),NROI(JJ) ,NSROI(JJ),NOVLP(JJ)
   & ,DISEFF(JJ,I),ADQAPP(JJ,I)
 10 FORMAT (9X,F6.3,3I8,2(10X,F10.4))
107 CONTINUE
    GO TO 116
100 CONTINUE
    STOP
    END
```